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TRITIUM (H^3)

A Bibliography of Unclassified Literature

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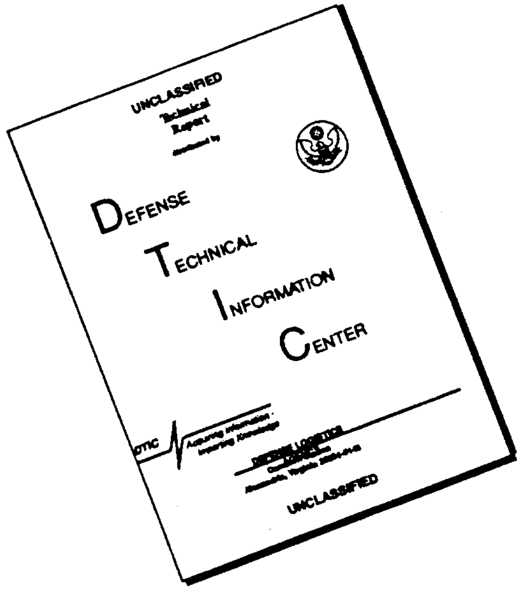

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Tritium (H^3)
A Bibliography of Unclassified Literature

compiled by

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ABSTRACT

This bibliography, arranged chronologically, consists of 250 references covering the period 1933 to 1950. Indexes to authors, subjects, and report numbers are included. The references listed cover primarily the nuclear and physical properties of tritium; a few articles on its use in tracer studies are included.

INTRODUCTION

The references included in this bibliography have been obtained by consulting Chemical Abstracts, Nuclear Science Abstracts, Science Abstracts: A. Physics Abstracts, and other sources of lesser importance. References given in many of the articles located were also checked and included.

Although the references listed are primarily on the nuclear and physical properties of the tritium atom or molecule, a number of references to the use of tritium in tracer studies have been included. Reference is also made to a few articles which report the construction and use of instruments which are particularly useful in detecting the β-radiation accompanying H^3 disintegration.

Those references which have been included without annotation were obtained from other bibliographies and reference lists which have not been checked in detail for applicability.

Indexes to authors, subjects, and report numbers follow the list of references which is divided by year of publication and further arranged alphabetically by senior author. In reviewing the references which are included, it should be remembered that the publication date does not necessarily correspond closely to the date of completion of research for those projects which were at one time classified.

Special thanks are due to Miss I. Lucy Faller of the Argonne National Laboratory for her review of references and suggestions of additional articles to be included in this bibliography.

1933

1 Latimer, W. M. and Young, H. A. "The Isotopes of H by the Magneto-Optic Method." Phys. Rev. (2), 44, 690(1933).

A new minimum is found in solns. of HCl and HBr in water contg. 2-4% H^2 and is ascribed to H^3.

2 Lewis, G. N. and Spedding, F. H. "A Spectroscopic Search for H^3 in Concentrated H^2." Phys. Rev. (2), 43, 964-6(1933).

The Balmer lines of H were photographed in a discharge through water vapor in which 2/3 of the H is H^2. $H^2\beta$ and $H^2\gamma$ could be photographed in two min., but no trace of H^3 lines appeared in 40 hrs. It is concluded that ordinary H cannot contain more than one part of 6 million of H^3. In a discharge tube with Al electrodes, H^2 cleans up selectively compared with H^1; this accounts for variations in spectroscopic estimates of abundance. Microphotometer curves of $H^2\alpha$ showing fine structure are given.

3 Wigner, E. Phys. Rev. (2), 43, 252(1933).

Wigner predicts that the binding energy of H^3 must exceed twice that of the deuteron.

1934

4 Bleakney, W. and Gould, A. J. "The Concentration of H^3 and O^{18} in Heavy Water." Phys. Rev. (2), 45, 281-2(1934).

A mass spectrograph analysis showed that in H_2 contg. 91 to 98% H^2, the ratio H^3:H^2 is less than 1:10^5. Accordingly, in ordinary H_2, H^3:H^2 is less than 2:10^9. O_2 collected from the cell which yielded 98% H^2 showed the same ratio of O^{18}:O^{16} as in ordinary water, contrary to the results of Washburn, Smith and Frandsen.

5 Bleakney, W., Harnwell, G. P., Lozier, W. W., Smith, P. T. and Smyth, H. D. "Production and Identification of Helium of Mass Three." Phys. Rev. (2), 46, 81-2(1934).

He^3 was produced from H^2 by treatment for 5 hrs. in a canal-ray discharge at 80 kv. and 10 ma. He^3 at a pressure of about 10^{-10} mm. was identified by its voltage-electron current curve. He^3 and H^3 are not radioactive. He^3 and He^5 could not be identified in ordinary He.

6 Dee, P. I. "Disintegration of the Deuteron." Nature 133, 564(1934).

Expansion-chamber photographs of the disintegration particles resulting from the bombardment of "heavy" $(NH_4)_2SO_4$ with deuterons show that 3 species are present--2 groups of equally charged particles of ranges 14.3 cm. and 1.6 cm. and neutrons of max. energy about 3,000,000 v. The lengths and direction of the cloud tracks give credence to the reaction: $H^2 + H^2 \rightarrow H^1 + H^3$. The neutron emission was similarly investigated by a study of recoil tracks originating in the gas phase of the chamber filled with 50% He in air. These tracks constitute an homogeneous group of max. energy about 1,800,000 v., which is in fair agreement with the reaction: $H^2 + H^2 \rightarrow H^3 + n^1$.

7 Goldhaber, M. "Probability of Artificial Nuclear Transformations and Its Connection with the Vector Model of the Nucleus." Proc. Cambridge Phil. Soc. 30, 561-6(1934).

Gamow's theory of artificial disintegration is used to explain the experimentally detd. fact that the reaction $Li^6 + H^1 \rightarrow He^4 + He^3$ is more probable than the reaction $Li^7 + H^1 \rightarrow He^4 + He^4$. The nuclear spins of H^3, He^3, Li^6, B^{10} and B^{11} are reported to be 1/2, 1/2, 1, 1 and 1/2, resp.

8 Goldsmith, H. H. "Disintegration of H^2 and the Stellar Abundance of H^2 and H^3." Phys. Rev. (2), 46, 78-9(1934).

The difference between the ratio H^2:H^1 in the earth (1:5000) and in the sun (probably 1:6 x 10^5) is due chiefly to the reaction $H^2 + H^2 \rightarrow H^3 + H^1$ and $H^2 + H^2 \rightarrow He^3 + n^1$, which should occur at temps. assigned to stellar interiors and during the time usually given for the age of the stars. H^3 should be much more abundant than H^2 in the stars; its spectrum is probably masked by lines due to other elements.

9 Harnwell, G. P., Smyth, H. D., VanVoorhis, S. N. and Kuper, J. B. H. "The Production of H^3 by a Canal-ray Discharge in Deuterium." Phys. Rev. (2), 45, 655-6(1934).

An appreciable amt. of H^3 has been accumulated by running a high-voltage discharge in H^2 at a low pressure and passing the canal ray from it into H^2 at a higher pressure. Three samples have been analyzed in the app. of Lozier, Smith and Bleakney.

10 Kurie, F. N. D. "A New Mode of Disintegration Induced by Neutrons." Phys. Rev. (2), 45, 904-5 (1934).

Cloud-chamber photographs of disintegrations by neutrons from Be show short, heavy tracks, therefore, of smaller charge than an α-particle, and are most likely protons. As only the angle between the tracks and the length of the nuclear track can be measured, the details of the disintegration process cannot be uniquely detd. Various possible reactions are discussed which involve neutron capture by N^{14} or O^{16} and the emission of protons, deuterons or H^3.

11 Lozier, W. W., Smith, P. T. and Bleakney, W. "H^3 in Heavy Hydrogen." Phys. Rev. (2), 45, 655(1934).

Tests for H^3 in a sample of nearly pure H^2 (about 1% H^1) gave an abundance ratio of 1 in 200,000. The ratio in natural H is probably of the order of 1:10^9 or smaller.

12 Taylor, H. S. "Protium - Deuterium - Tritium, the Hydrogen Trio." Sci. Monthly, 364-72(1934).

A review article.

13 Tuve, M. A., Hafstad, L. R. and Dahl, O. "A Stable Hydrogen Isotope of Mass Three." Phys. Rev. (2), 45, 840-1(1934).

By use of a sample contg. about 98% H^2 and a tube operating at 1100 kv., particles of mass 3 and range approx. 17.5 mm. were detected. Their abundance is approx. 1 ppm. of the sample of H^2.

1935

14 Alexopoulos, K. D. "The Disintegration of Deuterium by Deuterons." Naturwissenschaften 23, 817 (1935).

1935

Expts. with coincidental counters indicated that in the process of destruction of D nuclei by rapid deuterons: (A) $H^2 + H^2 = H^1 + H^3$, or (B) $H^2 + H^2 = He^3 + n^1$ no rapid γ rays are emitted, i.e., less than 1 γ quantum per 1000 neutrons made. For a deuteron current of 2μ amps., 140 ev. 1.7 x 10^7 neutrons are produced. A H_2-filled Wilson chamber gave the same order of magnitude in results. The yield of reactions A and B coincided perfectly at different values of deuteron energy (0-140 ev.).

15 Alexopoulos, K. D. "Disintegration of Lithium, Boron and Deuterium." Helv. Phys. Acta, 8.7., 601-36(1935).

Disintegration experiments are made by bombardment of Li, B, and H^2 with protons and deuterons of energy up to 140 kev. The products of disintegration are examined with α- and β-ray counters. With Li, proton bombardment gives rise to α-rays, the range of which is determined by absorption measurements. The α-ray groups of 1.8 cm. and 4 cm. range are estimated to have less than 3% of the intensity of the 8 cm. group. The probability of emission of γ-rays is found to be less than 1 quant per 2 disintegrations and the existence of the penetrating γ-ray reported by v. Traubenberg is not confirmed, although the apparatus is 22 times as sensitive. No γ-rays are observed on bombardment of Li with deuterons. Boron bombarded by either protons or deuterons gives less than 1 quant of γ-rays per 2 disintegrations. With H^2, bombardment by protons of 140 kev. energy gives no appreciable yield of neutrons or γ-rays. With deuteron bombardment, however, strong radiation is observed even at low potentials. Coincidence experiments with two counters show that there is about equal probability for the two reactions $H^2 + H^2 \rightarrow He^3 + n^1$ and $H^2 + H^2 \rightarrow H^3 + H^1$.

16 Bethe, H. A. "Masses of Light Atoms from Transmutation Data." Phys. Rev. (2), 47, 633-5(1935).

The masses of n^1, H^1, H^2, H^3, He^4, Li^6, Li^7, Be^9, B^{10}, B^{11}, C^{12}, C^{13}, N^{14}, N^{15} and O^{17} are calcd. from transmutation data, and on the basis O = 16.00000.

17 Budnizki, D. Z., Kurtschatow, I. W. and Latishev, G. D. "Disintegration of Lithium by Slow Neutrons." Physik. Z. Sowjetunion, 7.4. 474-83(1935).

Experiments with the Wilson chamber show that collisions between neutrons and lithium lead to a nuclear reaction according to the equation $Li^6 + n^1 = He^4 + H^3$, He^4 and H^3 being ejected in opposite directions with ranges of 20 and 65 mm. respectively in air at atmospheric pressure. The collision cross section for slow neutrons is shown to be 2 x 10^{-22} cm^2.

18 Chadwick, J. and Goldhaber, M. "Disintegration by Slow Neutrons." Proc. Cambridge Phil. Soc. 31, 612-16(1935).

All the light elements to Al were examined, using a parallel plate ionization chamber, for disintegration by slow neutrons from a Pb moderated Rn-Be source. Large effects were found in Li and B and a small effect was found in N_2. The reactions deduced are $Li^6 + n^1 \rightarrow He^4 + H^3$, $B^{10} + n^1 \rightarrow Li^7 + He^4$, and probably $N^{14} + n^1 \rightarrow B^{11} + He^4$.

19 Crane, E. J. "Report of Committee on Nomenclature, Spelling and Pronunciation [American Chemical Society]. Nomenclature of the Hydrogen Isotopes and Their Compounds." Ind. Eng. Chem., News Ed. 13, 200-1(1935).

The names hydrogen, deuterium and tritium and the symbols H, D, and T are preferred for the 3 isotopes for ordinary use, though protium or hydrogen-p or H^1, hydrogen-d or H^2, and hydrogen-t or H^3 are not objected to in appropriate connections. The term deuteron (for the deuterium nucleus) and the modified Boughton system for naming compds. are recommended.

20 Feenberg, E. "Neutron-Proton Interaction Part I. The Binding Energies of the Hydrogen and Helium Isotopes." Phys. Rev. (2), 47, 850(1935).

First applied a simple variational method, employing Gaussian wave function to the H^3 and He^4 nuclei.

21 Massey, H. S. W. and Mohr, C. B. O. "Interaction of Light Nuclei. II. Binding Energies of the Nuclei of ${}_1H^3$ and ${}_2He^3$." Proc. Roy. Soc. (London) A152, 693-705(1935).

The accuracy of the variation method in dealing with short-range interactions was studied by comparison with exact solns. for H^3. Trial functions in great variety were used in calcn. of the binding energy of H^3 on the assumption of zero interaction between neutrons. No function was found which gave a binding energy greater than 5.4 x 10^6 ev. (observed value 8.1 x 10^6). When an interaction is introduced between neutrons, the observed binding energy can be obtained if this attraction is even ⅓ of that between neutron and proton, on the assumption that the ranges of interaction in the 2 cases are comparable. This precludes the possibility of existence of a stable nucleus n_0. Similar calcns. for He^3 show that an anomalous attraction between 2 protons at small distances of the same order as that between 2 neutrons will give the observed binding energy, and consequently the nucleus He^2 must be unstable.

22 Neuert, H. "Ranges of Particles Emitted by Light Elements under Proton Bombardment." Physik Z. 36, 629-42(1935).

The paper is an account of the measurements, by the cloud-chamber method, of the ranges and range distribution of the particles emitted when elements are bombarded by protons having energies up to 200,000 ev. The particles from B were found to have a continuous range distribution, with a broad, pronounced maximum at 22 mm. and a weak maximum at 44 mm. The existence of a homogeneous group of particles of range 7.5 mm. was established in the case of Be. By using a hydrogen-filled cloud chamber, it was found that the short-range particles from Li consisted of two well-defined groups of range 12 and 8.2 mm., which are ascribed to H^3 and α-particles respectively. No nuclear particle emission was observed in the case of F.

23 Oliphant, M. L. E., Kempton, A. E. and Rutherford, E. "Nuclear Transformation of Beryllium and Boron, and the Masses of the Light Elements." Proc. Roy. Soc. (London) 150A, 241-8(1935).

Several of the reactions included indicate the prepn. of H^3.

24 Selwood, P. W., Taylor, H. S., Lozier, W. W. and Bleakney, W. "Concentration of Tritium." J. Am. Chem. Soc. 57, 780(1935).

1935

The results show that by further electrolysis of the H_2^2O prepns., now produced commercially, residues rich in H^3 can be readily assembled without significant loss of H_2^2 since the electrolytic gas so produced can be recombined to yield H_2^2O from which the H^3 has been partially removed.

25 Taylor, H. J. and Goldhaber, M. "Detection of Nuclear Disintegration in a Photographic Emulsion." Nature 135, 341(1935).

Notes include use of Li loaded emulsions and occurring triton production as radiation indicator.

26 Thomas, L. H. "Interaction Between a Neutron and a Proton and the Structure of H^3." Phys. Rev. (2), 47, 903-9(1935).

Considering the mass defect of H^2 to arise from the interaction of neutron and proton, calculation is made of the mass defect of H^3 assuming that (1) the force between two neutrons is negligible, (2) the force between the two neutrons and the proton may be compounded in the usual way, (3) the wave function is symmetrical in the position of the two neutrons. Comparison with the observed mass defect of H^3 provides a lower limit to the radius of interaction of neutron and proton and shows the interaction cannot simply arise from a singularity in configuration space. It is concluded that either (1) two neutrons repel each other with appreciable force, (2) the wave function is asymmetrical in the positions of the neutrons, or (3) the interaction between neutron and proton is not confined to distances small compared with 10^{-13} cm.

27 Yakovlev, K. P. "Disintegration of Lithium by Slow Protons." Z. Physik 93, 644-7(1935).

The yield, measured as function of the proton energy, agrees with the results of other observers.

1936

28 Burhop, E. H. S. "Atomic Disintegration by Particles of Low Energy." Proc. Cambridge Phil. Soc. 32, 632-6(1936).

A source of ions consisting of a low-voltage arc, yielding homogeneous ion currents of the order of 0.5 ma. at low potentials is described. With such a source, at. disintegrations have been observed with ion-beam energies of less than 8 kv. For the reaction $H^2 + H^2 \rightarrow H^3 + H^1$, the approx. value for the proportion of incident deuterons which produce protons in passing through a thick D target at 10 kv. was found to be 1 in 10^{12}. For the reaction $Li^7 + H^1 \rightarrow He^4 + He^4$, with a bombarding potential of 20 kv., a yield of about 1 disintegration in 10^{14} incident protons was obtained. α-particles from this reaction were detected with bombarding potentials of 17 kv.

29 Dolch, H. "Theory of the Lightest Nuclei." Z. Physik 100, 7-8, 401-39(1936).

Variational calcns. on H^2, H^3, and He^4 but his conclusions are invalid because of a poor solution of the two-body problem.

30 Dopel, R. "Nuclear Processes at the Mean Corpuscular Energy of Star Centers." Naturwissenschaften 24, 237(1936).

The reactions $H^2 + H^2 \rightarrow H^3 + H^1$ and $H^2 + H^2 \rightarrow He^3 + n^1$ were observed in a canal-ray app. below the usual potential

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limit. A NaOD target was bombarded with 2×10^{16} particles per sec. The protons were observed by scintillation, the neutrons by the Fermi electron method. Both types of particles were found down to 5 kv. potential. At this point the yield of protons was 10^{-16}; at 15 kv. the yield was 10^{-14}, the neutron yield being slightly higher. The potential of 5000 ev. corresponds to the interior of stars at 40×10^6 degrees temp.

31 Feenberg, E. and Share, S. S. "The Approximate Solution of Nuclear Three and Four Particle Eigenvalue Problems." Phys. Rev. (2), 50, 253-7(1936).

The problem of determining intranuclear forces from the mass defects of the hydrogen and helium isotopes is investigated under the assumption that the interaction potentials are proportional to a function $f(\alpha r^2)$ having the general form of a potential well and possessing the power series expansion $f(\alpha r^2) = 1 - \alpha r^2 + c_1(\alpha r^2)^2/2! - c_2(\alpha r^2)^3/3! + \ldots$ about the origin. With this assumption the Rayleigh-Schroedinger perturbation theory is applicable to the two, three and four particle eigenvalue problems. The perturbation calculation yields small corrections to the eigenvalues given by the "equivalent" two particle method. The corrections are checked very satisfactorily in a special case by means of a complicated variational calculation. Numerical results are given for two extreme forms of the neutron-proton model: Model I- Interaction between unlike particles only, Model II- Equal interactions between all pairs of particles. These results put close upper and lower bounds on the strength of the interaction between like particles in the model, intermediate between (I) and (II), which corresponds most closely to the experimental facts. H^3 is included in this treatment.

32 Japolsky, N. S. "Structure of Atomic Nuclei." Phil. Mag. (7), 22, 537-81(1936).

The structure of the neutron (n^1) and the nuclei (H^2), (H^3) and (He^3) and the α-particle (He^4) are discussed on the basis of the author's theory of elementary particles, according to which the elementary particles are certain axially symmetrical systems of Maxwell electromagnetic whirls or simply 'Whirls'. The question of interaction between the so-called "contrapolarise" Whirls of equal size (like the electron and the positron, or magneto-electron) and between identical Whirls when they are situated coaxially, which was considered in the previous papers only in general way, is discussed in detail. The transformation of energy and of mass, resulting from the interaction of elementary particles, is also discussed in greater detail. The holding forces and the kinetic and potential energies of the particles forming the nuclei are determined. The difference between the sum of masses of elementary particles forming the neutron and the discussed nuclei and their resultant masses is calculated on the basis of the above-mentioned theory of elementary particles. The result agrees very well with the latest experimental data.

33 Kempton, A. E., Browne, B. C. and Maasdorp, R. "Angular Distributions of the Protons and Neutrons Emitted in Transmutations of Deuterium." Proc. Roy. Soc. (London) 157A, 386-99(1936).

The angular distribution of the protons and neutrons emitted in the transmutations $H^2 + H^2 \rightarrow H^3 + H^1$, and $H^2 + H^2 \rightarrow He^3 + n^1$, is investigated. For the coordinates in which the center of gravity of the system is at rest it is found that the

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angular distributions are symmetrical about an angle of 90° to the direction of the incident particles, but that the intensity of emission at 0° is about 3/2 times that at 90°. Both distributions are relatively insensitive to the energy of the incident deuteron between 100 and 200 kev.

34 Oliphant, M. L. E. "Masses of Light Atoms." Nature 137, 396(1936).

Table shows mass of H^3 = 3.0171 and note on close agreement with He^3 mass.

35 Present, R. D. "Neutron-Neutron Forces in the H^3 Nucleus." Phys. Rev. (2), 50, 635-42(1936).

The variational procedure developed by Hylleraas in regard to the lower states of the He atom, already extended to the normal and excited states of H^2 is extended to the H^3 nuclear problem. The neutron-proton interaction is represented by $Be^{-2r/b}$, and the calculations are made for radii of interaction b of 1.0 and 2.0 x 10^{-13} cm., resulting in binding energies of H^3 of 11.0 and 9.5 mc^2 respectively; 11.5 mc^2 is deemed to be a very conservative upper limit for this energy.

36 Rotblat, J. "Ranges of Particles Emitted in the Disintegration of Boron and Lithium by Slow Neutrons." Nature 138, 202(1936).

Disintegration of B^{10} by slow neutrons yields α-particles and Li^7 nuclei with ranges of 8.18 and 3.64 mm., resp., and Li^6 yields α-particles and H^3 nuclei with ranges of 10.8 and 53.6 mm., resp. The corresponding energies of the α-particles are 1.43 and 1.93 ev., resp. Agreement is found with the calcd. value for Li but a large discrepancy for B may be due to an unknown mode of energy release. The cross section of the B nucleus for the capture of slow electrons is 8 times that of Li.

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37 Dolch, H. "Theory of the Lightest Nuclei." Z. Physik 104, 5-6, 473(1937).

The author points out an error in one of his earlier papers and notes that the agreement between theory and experiment which was there recorded, does not, in fact, exist.

38 Dopel, R. "Yield of the D → D-Nuclear Reaction." Ann. Physik 28, 87-96(1937).

An at. disintegration app. is described in which a secondary accelerating electrode is imposed, neg. with respect to ground. The observation takes place within a cage installed from high voltages. The yield from the processes $H^2 + H^2 \rightarrow H^1 + H^3$ and $H^2 + H^2 \rightarrow He^3 + n^1$ are detd. between 10 and 200 kv.; at 100 kv. it is about 10^{-9}. This is in agreement with the results obtained between 500 and 900 kv. Both D-nuclear reactions are observed down to a limiting potential of 5-8 kv.

39 Hylleraas, E. A. "Binding Forces Between Elementary Nuclear Particles." Z. Physik 107, 258-72 (1937).

A suitable potential is used for the system proton-neutron, for which the wave equation can be solved. The stationary states of the deuteron and the scattering of neutrons by protons are discussed. The ground states and excited states of H^3, He^3 and He^4 are calcd.

1937

40 Jozefowicz, E. "The New Discoveries of Isotopes, Especially Hydrogen Isotopes." Roczniki Chem. 17, 557-66(1937).

The present state of the science of isotopes is presented.

41 Kerchner, F., Neuert, H. and Laaff, O. "The Ionizing Power of Some Atom Nuclei Expelled by Nuclear Changes." Physik. Z. 38, 969-73(1937); Z. tech. Physik 18, 543-7(1937).

The ionizing powers of α-particles and deuterons formed by bombarding B with protons were detd. The deuterons have a range 0.5 to 1 mm. longer than that of the α-particles. Comparison is made with the ionization curve of H^3. The max. ionization powers of the three H isotopes are equal and about 45% of that for α-particles. He^3 formed in the reaction $Li^6 (p,\alpha) He^3$ has a max. ionizing power about 5% of that of the α-particle.

42 Margenau, H. and Warren, D. T. "Normal States of Nuclear Three- and Four-Body Systems." Phys. Rev. (2), 52, 790-98(1937).

A variational method employing orthogonal (Hermite) functions in linear combination is used for calculating the binding energies of H^3 ahd He^4, with the following choice of nuclear constants: A = 35.60 Mev.; a = 2.25 x 10^{-13} cm.; g = 0.20, and an error function potential. Two types of coordinates are used for H^3; (1) normal, (2) individual particle coordinates. Their advantages and disadvantages are discussed. With the use of a certain limited set of functions of normal coordinates this energy has been depressed from -6.21 Mev. in zeroth approximation to -7.21 Mev., while a suitable set of functions involving only individual particle coordinates reduced it from -6.16 Mev. to -6.84 Mev. The second Schrodinger perturbation is less effective than the latter scheme by 0.22 Mev. Functions of different symmetry, called into play by the Heisenberg operators, are found to contribute 0.07 Mev. on the basis of a modified variation method. He^4 has been treated only with the use of individual particle coordinates (Hartzee method). A similar group of functions lowers the energy from -24.81 Mev. in zeroth approximation to -25.85 Mev., which is better than the effect of Schrodinger's perturbation theory by 0.25 Mev. General estimates of convergence limits are given.

43 Rarita, W. and Present, R. D. "On the Nuclear Two-, Three- and Four-Body Problems." Phys. Rev. (2), 51, 788-98(1937).

The simplest nuclear Hamiltonian satisfying all present requirements includes a Majorana-Heisenberg interaction $[(1 - g)P + gPQ]V(\gamma)$ between unlike particles and an attractive singlet interaction between like particles which is equal to that for unlike particles. The experimental mass defects of H^2 and H^3 together with the cross section σ for slow neutron-proton scattering will determine the range b and depth B of the triplet well and the proportion g of Heisenberg force (we use throughout the potential $Be^{-2r/b}$). An exact analytic expression relating σ, b, B and g is derived for this potential and g is found to be very insensitive to σ. An exact solution of H^2 gives the relation between B and b. The final relation which fixes the parameters is furnished by a Ritz-Hylleraas variational treatment of H^3 with the above Hamiltonian and

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the wave function: $\psi = 2^{-\frac{1}{2}}\alpha_1(\alpha_2\beta_3-\alpha_3\beta_2)\phi_1 + 6^{-\frac{1}{2}}[\alpha_1(\alpha_2\beta_3 + \alpha_3\beta_2) - 2\beta_1\alpha_2\alpha_3]\phi_2$ where ϕ_1 and ϕ_2 each represents an exponential times a power series in the interparticle distances of proper symmetry (ϕ_2 is brought in by the Heisenberg term; the Breit-Feenberg operation is used for the small triplet like-particle interaction). The convergence of energies obtained from successive improvements in ψ is rapid and the eigenvalue may be closely estimated. After a relativistic correction is made we obtain: $b = 1.73 \times 10^{-13}$ cm; $B = 242$ mc^2 and $g = 0.215$. The binding energy of He^3 is obtained by the same method and the H^3 - He^3 difference is found to be 1.48 mc^2, agreeing well with experiment. The proton-proton scattering depth is checked to within 1 per cent. When applied to He^4, our potential gives approximately 20 per cent too much binding energy. Parallel calculations with the Gaussian and Morse curves lead to essentially the same result. No reasonable modification of the experimental data can explain more than a small fraction of the discrepancy.

44 Roberts, R. B. "Deuteron-Deuteron Reactions." Phys. Rev. (2), 51, 810-18(1937).

Excitation curves for the two deuteron-deuteron reactions have been determined; the reactions are $H^2 + H^2 = He^3 + n^1$, and $H^2 + H^2 = H^1 + H^3$. The yield of neutrons in the first case is found for energies of bombardment between 40 and 300 kev., and the yield of protons in the second case between 40 and 100 kev. The most satisfactory target used was D_3PO_4. The yield of fast neutrons measured in the forward direction for a thick D_3PO_4 target bombarded by 100 kev. deuterons was found to be equivalent to 44 mc. of Ra + Be per μA. The assumption of isotopic emission is made in calculating the results. The excitation curves for the two reactions coincide over the range 40-100 kev. The absolute yield of protons is found to be one proton per 6×10^6 deuterons after correcting for the stopping power of the target, but not for the anisotropy of the emission. No resonance is found in either excitation curve.

45 Rutherford, E. "Search for the Isotopes of Hydrogen and Helium of Mass 3." Nature 140, 303-5(1937).

A review.

46 Schiff, L. I. "Inelastic Collision of Deuteron and Deuteron." Phys. Rev. (2), 51, 783-8(1937).

Certain symmetry properties of the two deuteron-deuteron reactions are developed in a rigorous manner, and are shown to require a distribution of the reaction products for moderate incident deuteron energies of the form $A(1 + B\cos^2\theta)$ in the coordinate system in which the center of mass is at rest. This is shown to be in qualitative agreement with recent experimental data. The quantities A and B are evaluated approximately using a modification of Born's method and neglecting polarization of the deuterons; the quantitative discrepancies between theory and experiment are discussed. The theoretical relative yield from a "thick" deuterium target agrees well with the results of several experimenters; this quantity is influenced mainly by the Gamow factor, and is relatively independent of the details of the theory. The theoretical absolute yield is too large to agree with experiment.

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47 Share, S. S. and Breit, G. "Relativistic Effects for the Deuteron." Phys. Rev. (2), 52, 546-51(1937).

It is seen from tables and equations given that an appreciable spin-spin dependence of the neutron-proton interaction can be expected to arise. This spin dependence is of the wrong sign to account for the empirically known difference in energies of the singlet and triplet states of the deuteron. Its presence suggests that the spatial dependence of spin-dependent forces is not wholly the same as that of the other forces. The possibility of finding a simple equation in which the empirical spin dependence will be a natural consequence is still open. It is shown that the relativistic correction to the kinetic energy is only a small part of the corrections called for by invariance. The relativistic refinements made so far in the combined theory of H^2 and H^3 are shown to be questionable from this point of view, as well as on account of the possible presence of terms in relative moment which are not determined by requirements of invariance alone.

48 Williams, J. H., Haxby, R. O. and Shepherd, W. G. "Disintegration of Beryllium and the Masses of the Beryllium Isotopes. Phys. Rev. (2), 52, 1031-4 (1937).

The following reactions have been studied up to bombarding energies of 250 kev.: $Be^9 + H^1 \rightarrow Be^8 + H^2$ and $Li^6 + He^4$; $Be^9 + H^2 \rightarrow Li^7 + He^4 + Q_2$; $Be^9 + H^2 \rightarrow Be^8 + H^3 + Q_3$, $Be^9 + H^2 \rightarrow Be^{10} + H^1 + Q_4$. The efficiency curves are smooth and regular. The abs. yields from a thick target of Be per incident ion of 212 kev. energy are: 4×10^{-7}, 1×10^{-9}, 2×10^{-10} and 2×10^{-11}, resp.; accuracy is $\pm 50\%$. The values of Q_2, Q_3, Q_4 as detd. from range measurements of the disintegration products are 6.95, 4.32 and 4.44 Mev., resp., and the masses of Be^8, Be^9, Be^{10} are 8.0081, 9.0150 and 10.0168.

49 Yukawa, H. and Sakata, S. "Theory of Collision of Neutrons with Deuterons." Proc. Phys. Math. Soc. Japan 19, 542-51(1937).

The problem of the neutron-deuteron collision is reduced to a simple form by taking the structures of H^2 and H^3 into account and neglecting the forces depending explicitly on the spin. The form of the effective potential hole is determined by comparing the estimated value of the cross section of scattering of slow neutrons by deuterons with that obtained experimentally. The cross section of capture is found to be small in agreement with the experiment. The energy dependence of the scattering cross section is also discussed. The theory of Fermi concerning the effect of the chemical binding on the scattering of slow neutrons is extended to the more general case and a necessary limitation of the theory is discussed. The cross section for thermal neutrons is found to be nearly twice as large as that for neutrons of several volts. Theoretical reasons for the small contribution of the deuteron to the slowing down are considered.

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50 Bonner, T. W. "Formation of an Excited He^3 in the Disintegration of Deuterium by Deuterons." Phys. Rev. (2), 53, 711-13(1938).

The energy distribution of the neutrons from the reaction $H^2 + H^2 \rightarrow He^3 + n' + Q_1$ was studied. Two homogeneous neutron groups with energies of 1.08 and 2.50 Mev. have been observed at 90° to the 0.11 Mev. deuterons. The emission

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of 1.08 Mev. neutrons has been found to be approx. 1/10 as likely as the emission of 2.50 Mev. neutrons. The corresponding values of Q_1 are $Q_1^\circ = 3.29 \pm 0.08$ Mev. and $Q_1^1 = 1.40 \pm 0.11$ Mev. The low energy group results when the He^3 is left excited to a level 1.89 ± 0.11 Mev. The mass of He^3 has been calcd. from the value of Q_1° and the mass spectrographic value of $H^2 = 2.01473$. The result is $He^3 = 3.01700$. This result indicates that H^3 may spontaneously disintegrate into He^3 with emission of an electron.

51 Bower, J. C. "Variation of Ionization with Range of α-particles, Deuterons and T^3 Particles." Proc. Cambridge Phil. Soc. 34, 450-8(1938).

Photometrical detns. of the variation of d. along photographs of expansion-chamber tracks have enabled the positions of max. ionizing efficiency for single α-particles, protons, deuterons and H^3 particles to be detd. when they have 3.7, 0.78-9, 1.47 and 2.39-44 mm. residual range in air, resp. The distance of the position of max. ionizing efficiency from the end of the particle range is shown to be approx. in the ratio of the particle mass in the case of the particles H^1, H^2, and H^3, viz., 0.78:1.47:2.39, and it should be possible to identify each of these particles by this method.

52 Flugge, S. "Effective Cross Sections in Reactions Between Very Light Atomic Nuclei." Z. Physik 108, 545-79(1938).

Collision problems are treated, up to those involving four elementary particles in two atomic nuclei. Empirical data exist for the elastic scatter of neutrons and protons with deuterons. The scatter cross sections calcd. are of the order of 10^{-24} sq. cm. and fall slowly with increasing energy. The calcd. values are somewhat smaller than the observed. For the scattering of protons with an energy of 830 kv., when scattered by deuterons, the angular distribution is calcd. and compared with the exptl. values. Taking the $H^2 + H^2$ reaction as the simplest case involving four elementary particles, the transition probability from a $H^2 + H^2$ initial state to a $H^3 + H$ end state is worked out. There is a strong reduction in amplitude for small sepns. which, related to the shortening of wave length, results in giving a corss section in this region 10^{-4} that previously evaluated by Dolch. One thus reaches a value of the order of those observed. In addn., certain selection rules are discussed relating to the characteristic deviations from spherical symmetry in the distribution of the disintegration particles in the $H^2 + H^2$ reaction.

53 Golovin, I. N. "Nuclear Forces and Bond Energy of H^3 and He^3." J. Exptl. Theoret. Phys. (U.S.S.R.) 8, 658-70(1938).

For four-component exchange forces, the nuclear energy calcd. for H^3 is homogeneous for all particles. The bond energy of H^3 (8.46 Mev.) argues against the existence of homogeneous forces between like and un-like heavy particles.

54 Hudspeth, E. and Bonner, T. W. "Observation of H^1 and H^3 Ranges from the Disintegration of Deuterium by Deuterons." Phys. Rev. (2), 54, 308-9(1938).

In the reaction $H^2 + H^2 \rightarrow H^3 + H^1$, both end products give single (range) groups with mean ranges of 1.31 ± 0.10 and 14.7 cm., resp. The energies of the particles are calcd.

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55 Livingston, M. S. and Hoffman, J. G. "Slow Neutron Disintegration of B^{10} and Li^6." Phys. Rev. (2), 53, 227-33(1938).

The disintegration of B^{10} by slow neutrons is found to result in two groups of alpha-particles, of ranges 0.80 ± 0.03 and 0.66 ± 0.05 cm. and with relative intensities 1 : 3, corresponding to disintegration into the ground state of the Li^7 product nucleus and the 0.44 Mev. excited state, respectively The reaction energies obtained from these ranges with the best available range energy relation check well with those computed from atomic masses if a mass of B^{10} is used which is consistent with other nuclear disintegrations. The slow neutron disintegration of Li^6 results in H^3 particles of 5.90 ± 0.06 cm. range, indicating a reaction energy of 4.86 Mev. This is in disagreement with the value obtained from atomic masses and suggests errors in the mass values or the proton range energy relation. Techniques for the measurement of very short particle ranges are described, including methods for the determination of the depth of penetration into the recording ionization chamber.

56 Myers, R. D. "The Angular Distribution of Resonance Disintegration Products." Phys. Rev. (2), 54, 361-7(1938).

Theoretical and mathematical. The results are applied to the reactions: $H^2 + H^2 \rightarrow H^3 + H^1$; $B^{11} + H^1 \rightarrow Be^8 + He^4$; $Li^7 + H^1 \rightarrow He^4$; $Li^6 + H^2 \rightarrow Li^7 + H^1$.

57 Myers, F. E. and Langer, L. M. "Search for an Excited State of the H^3 Nucleus." Phys. Rev. (2), 54, 90(1938).

No exptl. evidence for an excited state of H^3 was found.

58 Neuert, H. "The Angle Distribution of the Protons Emitted in the Process $D + D = H^3 + H^1$." Naturwissenschaften 26, 429(1938).

On bombarding D with D canal rays the no. of protons emitted in different directions varies. A potential range of 35 to 90 kv. was used and the angle distribution detd. by proportional counters. The ratio of no. perpendicular to the latter is about 1.5 at 100-120 kv., 1.17 at 35 kv.

59 Neuert, H. "The Angular Distribution of Nuclear Fragments in the Reactions $D + D = H^3$ p and B^{11} + p = $Be^8 + \alpha$." Physik. Z. 39, 890-2(1938).

The angular distribution for both reactions depends on the voltage used. The higher the voltage, the greater the no. of particles ejected at small angles.

60 Reinsberg, C. "The Angular Distribution in Nuclear Disintegration." Physik 108, 189-94(1938).

The theory is applied to the following reactions. $H^2(d,p)H^3$, $H^2(d,n)He^3$, $Li^6(d,p)Li^7$, $Li^6(p,\alpha)He^3$, $Li^7(p,\alpha)He^4$, $B^{11}(p,\alpha)Be^8$. There is excellent agreement between the exptl. data and between those calcd. from the theory presented.

61 Reinsberg, C. "The Angular Distribution in Nuclear Disintegrated Particles." Z. Physik 110, 765(1938).

This is a correction to his article which appeared in Z. Physik 108, 189-94(1938).

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62 Rumbaugh, L. H., Roberts, R. B. and Hafstad, L. R. "Nuclear Transmutations of Li Isotopes." Phys. Rev. (2) 54, 657-80(1938).

Yield curves have been obtained for eight of the more important reactions of Li^6 and Li^7 produced by proton and deuteron bombardment in the energy range from 200 to 1000 kev. Each curve was obtained with an accuracy of about 5%, and a set of intercomparisons served to determine the relative yields between the different reactions within 20%. A special set of observations on a single reaction then gave the absolute yield for all the reactions within a factor of about three. Observations on the reaction $Li^6 + n \rightarrow He^4 + H^3$ gave a value of 4.97 Mev. for the reaction energy as compared to a value of 4.56 Mev. derived from the masses involved.

63 Sen, B. M. "Nuclear Structure of Light Atoms." Indian J. Phys. 11, 427-32(1938).

It is suggested that the nucleus may be regarded as forming a cryst. structure rather than an ensemble of protons and neutrons and as a static or at least quasistatic system rather than dynamic. Calcns. from mass defects give distances between elementary particles in the nucleus of the order of 10^{-14} cm., the value generally accepted. The structures of the isotopes of H, He and Li are considered.

64 Share, S. S. "Excited States of the H^3 and He^4 Nuclei." Phys. Rev. (2), 53, 875-9(1938).

Calculations were made with trial wave functions corresponding to such excited states of H^3 and He^4 which, in the Hartree approximation, would contain one or two particles excited into the P shell. If only one particle is excited there is no state which would be completely symmetrical in space coordinates and if two particles are excited only an S and a D state have this property. On account of the supposed predominance of the Majorana exchange forces in the nuclear Hamiltonian, these should be the lowest excited states in H^3 while in He^4 the P state in which only one particle would be excited in the Hartree picture lies close to these. No stable excited states are indicated for either of the nuclei when the forces are of the exchange type unless the range of force is much greater than the accepted range. Several improved forms of the D state wave function were tried but they failed to lower the energy sufficiently to make the states stable.

65 Sherr, R., Smith, L. G. and Bleakney, W. "The Existence of H^3." Phys. Rev. (2), 54, 388(1938).

Exptl. work is described which shows that the authors have no evidence for the existence of H^3, and that the former interpretation of similar data was erroneous.

66 Wilson, A. H. "The Binding Energy of the Hydrogen Isotopes." Proc. Cambridge Phil. Soc. 34, 365-74 (1938).

The wave equation for the deuteron in its ground state is solved on the assumption that the mutual potential energy of a neutron and a proton is of the form $r^{-1}e^{-\lambda r}$. The binding energy of the H^3 isotope is calcd. approx. by the variation method.

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67 Alvarez, L. W. and Cornog, R. "He^3 in Helium. Phys. Rev. (2), 56, 379(1939).

The 60-inch cyclotron was filled with He and used as a mass spectrograph; the relative intensities were 10^{12} for He^4, 10^3 for He^3, none for He^5. In H^2, H^3 was not observed.

68 Alvarez, L. W. and Cornog, R. "Helium and Hydrogen of Mass 3." Phys. Rev. (2), 56, 613(1939).

The isotopic ratios He^3/He^4 are 10^{-8} for gas-well He and 10^{-7} for atm. He. He^{+++} ions, at 24 Mev., induce a radioactivity in Si; ${}_{14}Si^{28} + {}_2He^3 \rightarrow {}_{15}P^{30} + {}_1H^1$; ${}_{15}P^{30} \rightarrow {}_{14}Si^{30} + e^+$. H^3 has a definite activity of long half-life.

69 Brown, F. W. "The Binding Energy of H^3." Phys. Rev. (2), 56, 1107-10(1939).

The consts. in the meson type of potential were calcd. by fitting the scattering data for the scattering of slow electrons by protons and the binding energies of H^2 and H^3.

70 Chernyaev, V. I. "The Hydrogen Isotope of Mass 3." Uspekhi Fiz. Nauk 21, 466-77(1939).

A review.

71 Haxby, R. O., Allen, J. S. and Williams, J. H. "The Angular Distribution of the Disintegration Products of Light Elements." Phys. Rev. (2), 55, 140-6(1939).

The following reactions were studied: $Li^6 + H^2 = {}_2He^4$, $H^2 + H^2 = H^3 + H^1$, $B^{11} + H^1 = Be^8 + He^4$, $B^{11} + H^1 = {}_3He^4$. The Li reaction was found to be spherically sym.

72 Gamow, G. "Nuclear Reactions in Stellar Evolution." Nature 144, 575-7, 620-2(1939).

Values for Q (energy of reaction) and Γ (Γ/h = probability of reaction after penetration of the potential barrier) are tabulated for nuclear reactions of H^1 with H^1, H^2, H^3, Li^6, Li^7, Be^9, B^{10}, B^{11}, C^{11}, C^{12}, C^{13}, N^{14}, N^{15}, O^{16}, F^{19}, Ne^{22}, Mg^{26}, or Si^{30}. It is shown that energy production in the sun is due to the cycle: $C^{12} + H^1 \rightarrow N^{13} + h\nu$; $N^{13} \rightarrow C^{13} + e^+$; $C^{13} + H^1 \rightarrow N^{14} + h\nu$; $N^{14} + H^1 \rightarrow O^{15} + h\nu$; $O^{15} \rightarrow N^{15} + e^+$; $N^{15} + H^1 \rightarrow C^{12} + He^4$($C^{12}$ and N^{14} are catalysts for the reaction ${}_4H^1 \rightarrow He^4 + 3h\nu + 2e^+$). The positions on the Hertzsprung-Russell diagram of those stars which derive their energy from the C-N cycle and the direction of motion of the sun on that diagram during its evolution are discussed. The positions on the diagram occupied by red giant stars and variable stars and the positions of stars whose sources of energy are principally B^{10}, B^{11}, Be^9, Li^7, Li^6, H^3 and H^2 reactions are indicated. The course of stellar evolution is briefly discussed. The problem of stellar energy sources and the main features of stellar evolution can be considered as practically solved.

73 Myers, F. E., Huntoon, R. D., Shull, C. G., and Crenshaw, C. M. "Search for a Short Range Group of Protons in the D - D Reaction." Phys. Rev. (2), 56, 1104(1939).

Bonner's recent confirmation of previous experiments indicates strongly the presence of a low energy group of neutrons in the reaction $H^2 + H^3 \rightarrow He^3 + n^1$. The tentative explanation of this group is that the He^3 nucleus is left in an excited state about 1.9 Mev. above the ground state. Such an excited state cannot readily be accounted for theoretically, and a search for gamma-rays, internal conversion electrons

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and positrons has led to negative results within an experimental error far below the expected intensities. In spite of these difficulties, the evidence for a low energy neutron group appears strong, and further study of the D - D reaction is desirable. If one assumes that the only difference between the neutron emitting reaction and the proton emitting reaction is the Coulomb barrier encountered in the latter case, then there should be a corresponding short range group of protons, presumably accompanied by an H^3 nucleus in an excited state. These protons would be expected to have a range of about 5 cm. at 90° to an incident beam of 200-kev. deuterons. Myers and Langer, and Hudspeth and Bonner found none ejected in a small solid angle approximately at right angles to the beam of incident deuterons. Since the angular distribution of the protons and neutrons is not spherically symmetrical there must be in some of these nuclear reactions one or more quanta of orbital angular momentum and as has been pointed out to one of us by Ellett there is a possibility that these interactions might be the ones to give rise to the excited H^3. Further if the reaction responsible for the excited H^3 were of the p type or higher odd order there would be no short range protons ejected at 90° and the negative result for measurements at 90° becomes inconclusive. From these considerations and because of the fundamental nature of any information about the simplest of the nuclear reactions it seemed advisable to extend the search for short range protons to other angles and to higher bombarding energies.

74 Neuert, H. "Angular Distribution of Transmuted Particles in Transformation Processes of Light Nuclei." Ann. d. Physik, 36, 437-61(1939).

Experiments have been made to discover whether the angular distribution of transmuted particles is connected with the energy of the colliding particles. The processes studied were $Li^6(H^2,p)Li^7$, $H^2(H^2,p)H^3$, and $B^{11}(p,\alpha)Be^8$, energies up to 300 kev. being used. In the process $Li^6(H^2,p)Li^7$, the abundance ratio for a very thin film is 1.9-2 for energies of 180 and 290 kev. In the case of $B^{11}(p,\alpha)Be^8$ there is a strong resonance-like maximum of the abundance ratio for 170 kev.

75 Van Allen, J. A., Ellett, A. and Bayley, D. S. "Cross Section for the Reaction $H^2 + H^2 \rightarrow H^1 + H^3$ with a Gas Target." Phys. Rev. (2), 56, 381(1939).

The following cross sections (10^{-26} sq. cm.) were found at various bombarding energies: 1.4 at 50 kev., 1.6 at 100, 2.5 at 200, 3.8 at 330 and 4.9 at 390 kev. The probable error is 6-8% due to all causes except contamination with H^1. This contamination probably is less than 20%; the tabulated cross sections are low by the corresponding amt.

76 Way, K. "Simple Picture of Binding Energies of H^3 and He^5." Phys. Rev. (2), 56, 556-61(1939).

It is shown that an approximate application of Wheeler's method of resonating groups to the nuclei, H^3 and He^5, makes it possible to evaluate the magnitude of different contributions to the total energy. The energy expressions are separated into terms representing the internal energy of a favorable sub-group, the kinetic energy of a particle outside the sub-group, and its "ordinary" and "velocity dependent" interaction with the sub-group. For H^3 the sub-group is the deuteron and for He^5 the α-particle. The results indicate considerable polarization of the deuteron and little polarization of the α-particle. The total energies found were $E(H^3)$ = -6.58 mMU and $E(He^5)$ = -19.51 mMU (for the most reasonable value of one parameter since no true minimum was found for He^5). These results are compared with those of other methods. The current two-body exchange forces were used. The approximate method is quick and easy to handle. Application of the complete resonating group method to H^3, however, proved to be very laborious and difficult to make accurate. By this procedure $E(H^3)$ came out -6.68 mMU. The smallness of the improvement over the approximate method is attributed to the fact that the complete method does not take polarization into account. The calculated ground state energy for He^3 was -5.88 mMU by the approximate method and 5.94 mMU by the complete method. No bound excited state was found.

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77 Alvarez, L. W. and Cornog, R. "Radioactive Hydrogen." Phys. Rev. (2), 57, 248(1940).

Further tests have confirmed our suggestion that H^3 produced in the $H^2 + H^2$ reaction is radioactive. We have bombarded heavy water with deuterons and observed the concentration of the radioactive hydrogen in electrolysis. This, together with the fact that no activity can be detected in the electrolytic oxygen, indicates that radioactive body must be a heavy isotope of hydrogen. The yield of active atoms, as determined by Geiger counter experiments, is about equal to the number of neutrons produced in the $H^2 + H^2$ reaction, leading support to the assignment of mass 3. The half-life is being measured on three samples, one of which has been followed for 80 days; the best value at present is 150 ± 40 days. The average energy of the beta-rays has been estimated from the ratio of the number of active atoms to the number of ion pairs formed in a given volume of gas, and independently from range measurements. These rough measurements both give about 10 kev. A precision measurement by electrostatic methods is now in progress.

78 Alvarez, L. W. and Cornog, R. "Radioactive Hydrogen — A Correction." Phys. Rev. (2), 58, 197 (1940).

The first sample of radioactive hydrogen was placed in the only chamber available at the time. To guard against the possibility that H^3 would diffuse through a rubber tube connected to the chamber, three specially designed chambers were constructed of brass and glass. Enough data have been accumulated from one of these to show that our previously reported decay was due to diffusion. No appreciable decay has been observed in five months with the improved chamber. If, as O'Neal and Goldhaber have suggested, McMillan's Be + H^2 activity was really H^3, we can use his estimate of the life as greater than ten years. This agrees better with the extrapolated yield of the $H^2 + H^2$ reaction. The half-life will have to be computed from accurate data of that type, when they are available from laboratories equipped for such work. We observed some time ago that deuterium recovered from the cyclotron pumping system was more radioactive than could be explained by the $H^2 + H^2$ reaction. This is now explained in terms of the Be + H^2 reaction. The enhanced specific activity of H^3 samples now made through the Be reaction increases the sensitivity of our electrostatic apparatus for measuring the upper limit, which is now in operation.

1940

79 Borst, L. B. "Search for a Neutron-Deuteron Reaction." Phys. Rev. (2), 57, 659(1940).

An attempt was made to prepare H^3 by the bombardment of heavy water with neutrons slowed in paraffin. The abs. cross section for the reaction $H^2 + n^1 = H^3$ is 2×10^{-28} sq. cm.; the max. value is 3×10^{-28} sq. cm.

80 Huntoon, R. D., Ellett, A., Bayley, D. S. and Van Allen, J. A. "Distribution in Angle of Protons from the Deuteron-Deuteron Reaction." Phys. Rev. (2), 58, 97-102(1940).

Measurements of the angular distribution of the protons emitted in the reaction $H^2 + H^2 \rightarrow H^3 + H^1$ have shown that the distribution is markedly anisotropic and that it is probably of the form $1 + A \cos^2\theta$ in the center-of-mass coordinate system. Different investigators have not obtained concordant results on the value of A nor on the question of its energy dependence. Satisfactory interpretation of their measurements is made difficult, however, by two practical factors inherent in the use of thick deuterium targets: (1) an uncertainty in the actual collision energy of an incident deuteron caused by surface contamination, and (2) an uncertainty in the character of the target—that is, in the distribution of deuterium and in the stopping power during prolonged bombardment. The seriousness of these uncertainties is even greater since both yield and angular distribution data on the same or an equivalent thick target must be known as a function of bombarding energy in order to deduce thin-target (i.e., theoretically interesting) angular-distribution data. A suitably arranged gaseous target is free of these uncertainties and is very attractive as an experimental possibility. It has been found feasible to use such a target of deuterium gas in a careful study of the angular distribution of the protons at several bombarding energies. The simplicity and importance of the deuteron-deuteron reaction recommend such a study.

81 O'Neal, R. D. and Goldhaber, M. "The Decay Constant of H^3." Phys. Rev. (2), 58, 574-5(1940).

The decay const. λ of H^3 is too small to be detd. conveniently from the decay curve. By producing a known no. of H^3 nuclei, and observing the no. which decay in unit time, it was found that $\lambda = 7 \times 10^{-10}$ sec.$^{-1}$ $\pm$ 25%, or $H^3 = 31 \pm 8$ yrs.

82 O'Neal, R. D. and Goldhaber, M. "New Method for the Production of Radioactive Hydrogen of Atomic Weight Three." Trans. Illinois State Acad. Sci. 33, No. 2, 187-8(1940).

A Be target which had been bombarded with deuterons in a cyclotron was etched with dil. H_2SO_4, and the H evolved was found to be highly radioactive—approx. 3000 counts per min. There was no noticeable decay in the activity of the product; this fact indicated a high half-life period. The active H must have been formed according to the reaction, $Be^9 + H^2 \rightarrow Be^8 + H^3$, for the range of the radiation was 8 cm. The range of radiation from $H^2 + H^2 \rightarrow H^3 + H^1$ is only 1.6 cm.

83 O'Neal, R. D. and Goldhaber, M. "Radioactive Hydrogen from the Transmutation of Beryllium by Deuterons." Phys. Rev. (2), 57, 1086(1940).

In the course of an investigation of the β-rays emitted from an "aged" Be target, which had been previously bombarded with 1-Mev. deuterons, the maximum energy was found to be in good agreement with the value of 13 $\pm$ 5 kev. reported by Libby and Lee. These β-rays had been ascribed to Be^{10}. However, in an attempt to identify chemically the radioactive isotope, we were unable to detect any activity in the beryllium precipitate. It appeared therefore plausible to ascribe the activity to H^3, which emits β-rays of similar maximum energy, and which might have been formed by the reaction $Be^9 + H^2 \rightarrow Be^8 + H^3$. We tested this assumption by showing that a radioactive gas could be extracted from the Be target, either by heating the target or by dissolving it in sulphuric acid. Further tests excluded the possibility that an appreciable fraction of the H^3-particles obtained had been formed by the disintegration of H^2 adsorbed on the surface of the Be target.

84 Seaborg, G. T., Wahl, A. C. and Kennedy, J. W. "Thermal Diffusion Separation of Radioactive and Ordinary Hydrogen Isotopes." J. Chem. Phys. 8, 639-40(1940).

The sepn. factor of a thermal diffusion column was found to be substantially the same at moderate and at extremely small mol. fractions, from tests made on mixts. of H with H^2 and of H^2 with H^3. The sepn. factor increases with the temp. of the hot wire. When 2 diffusion columns were connected in series the sepn. factor was the product of the individual sepn. factors; however, the time required to attain equil. was about 10 times as long as for a single column.

85 Sirkar, S. C. and Mukherji, K. C. "The Nuclear Mass and Radioactivity of ${}_1H^3$." Science and Culture 5, 443(1940).

The data of Alvarez and Cornog and of Livingston and Bethe are recalcd. and shown to be compatible. H^3 emits one electron with small kinetic energy and is transformed into He^3.

86 Stephens, W. E. "The Effect of the Coulomb Force on Binding Energies of Light Nuclei." Phys. Rev. (2), 57, 938-9(1940).

Exptl. values and values of Coulomb differences calcd. on 4 different assumptions are assembled for He^3-H^3, Li^5-He^5, Be^7-Li^7, B^9-Be^9, C^{11}-B^{11}, N^{13}-C^{13}, O^{15}-N^{15}, F^{17}-O^{17}, Ne^{19}-F^{19}, Na^{21}-Ne^{21}, Mg^{23}-Na^{23}, and Al^{25}-Mg^{25}. The "nuclear radius" $R = 1.45 \times 10^{-13}\ A^{1/3}$ cm. fits all this group but B^9 and Li^5. 16 references.

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87 Berger, A. "Transformation of Lithium by Slow Neutrons." Z. ges. Naturw. 7, 297-304(1941).

When Li is bombarded with thermal neutrons, the reaction $Li^6 + n = He^4 + H^3$ occurs. The range of He^4 and H^3 particles was detd. by means of a proportional counter with a reticular jacket which was placed inside a large coaxial cylinder. On the inside of this cylinder LiF was dusted. Beside the cylinder was a 30-millicurie Be-Rn prepn. The app. was surrounded by 12 cm. of paraffin. The fragments of the Li nucleus crossed the space between the Li layer and the counter tube, as well as the reticular jacket, and were registered by the tube. By varying the gas pressure within the cylinder the range, hence the energy, of the fragments was detd. A direct detn. of the energy of He^4 was made with

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a proportional counter whose inner wall was covered with LiF. The counter was calibrated by means of α-particles from ThC^1. The mass of H^3 is 3.01683 ± 0.00009.

88 Borst, L. B. "Deuteron-Tritium Reaction in Nitrogen." Phys. Rev. (2), 59, 941(1941).

The reaction $Be^9(d,H^3)Be^8$ has been established and there are indications of similar reactions in Cu^{63} and Ag^{107}. It therefore seemed desirable to look for other examples of this reaction. The reaction $N^{14}(d,H^3)N^{13}$ has been established and its excitation function measured. The threshold was found to be 6.8 ± 0.1 Mev. Calculations from the masses give Q = 4.54 Mev., so that the H^3 nucleus emerges with an energy of 2.2 Mev. The value of the potential barrier involved is 2.6 Mev. Aluminum was similarly studied, but no indication of the reaction was found with 8.2 Mev. deuterons. In this case Q = -5 Mev., and the potential barrier, 3.4 Mev., so that by analogy the threshold should be about 8 Mev., and consequently difficult to observe at the energy used.

89 Brown, S. C. "β-ray Energy of H^3." Phys. Rev. (2), 59, 954-6(1941).

The max. energy of the H^3 β-ray spectrum has been measured by its absorption in He. The detector was a screen-wall counter with He at atm. pressure flowing through it at all times. The max. range of the H^3 β-rays in He was determined as 13 ± 1mm. corresponding to a max. energy of 9.5 ± 2.0 kev.

90 Cornog, R. and Libby, W. F. "Production of Radioactive Hydrogen by Neutron Bombardment of Boron and Nitrogen." Phys. Rev. (2), 59, 1046(1941).

Satd. aq. solns. of boric acid and of NH_4NO_3 were bombarded with fast neutrons. The H_2O showed an activity due to H^3. The possible reactions are: (1) $B^{10} + n^1 \rightarrow B^{11} \rightarrow Be^8 + H^3$ + 0.2 Mev., $Be^8 \rightarrow He^4 + He^4$; (2) $B^{11} + n^1 \rightarrow B^{12} \rightarrow Be^9 + H^3$ - 9.6 Mev.; (3) $N^{14} + n^1 \rightarrow N^{15} \rightarrow C^{12} + H^3$ - 4.3 Mev.; (3a) $N^{14} + n^1 \rightarrow N^{15} \rightarrow He^4 + He^4 + H^3$ - 11.5 Mev.; (4) $N^{15} + n^1 \rightarrow N^{16} \rightarrow C^{13} + H^3$ - 10.1 Mev. The upper neutron energy is 20 Mev. The fast neutron cross section for the production of H^3 is 10^{-26} sq. cm. for reactions 1, 2, 3 and 3a.

91 Golovin, I. N. "Physics of the Atomic Nucleus." Uspekhi Khim. 10, 93-100(1941).

A review covering the latest developments on the disintegration of mesons, existence of the neutrino, the He^3 isotope, β-disintegration of H^3, disintegration of the uranium isotopes, the chem. sepn. of nuclear isomers, nuclear forces and the structure of the neutron.

92 Krishnan, R. S. "Deuterium-Tritium Reaction in Fluorine." Nature 148, 407-8(1941).

The (d,H^3) reaction, which has been shown to occur in Cu, Ag and Sb, also occurs in F. NaF was bombarded with 9 Mev. deuterons. The F fraction showed a short period activity, and an intense positron activity with a period of 112 ± 2 min. This and absorption data identify it to be F^{18}: $F^{19}(d,H^3)F^{18}$. The threshold is near 6 Mev. With 8.8 Mev. deuterons, the cross section for the formation of F^{18} from F is (3.9 ± 0.4) x 10^{-27} sq. cm.

93 Krishnan, R. S. and Banks, T. E. "A New Type of Disintegration Produced by Deuterons." Proc. Cambridge Phil. Soc. 37, 317-23(1941).

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Pure Cu is bombarded with deuterons of 9 Mev. energy. Positron activity attributed to Cu^{62} is reported, the energy exceeding 2 Mev. and the half life being 10.5 min. Excitation functions are detd. for Cu^{62} and Cu^{64}. Pure Sb samples from independent sources are irradiated and the decay of the activity produced is measured. A positron energy of max. exceeding 1 Mev. and period 13.5 min. is recorded. Chem. sepn. shows that the active fraction is Sb. The activity is attributed to Sb^{120}. Excitation functions are detd. for Sb^{120} and Sb^{122}. The Sb^{120} curve exhibits resonance peaks. The reactions producing Cu^{62}, Ag^{106} and Sb^{120} are of a new type. It is concluded that they are of the form A^x $(H^2, H^3)A^{x-1}$ through the formation of a compound nucleus of the Bohr type.

94 Nielsen, C. E. "The Energy Spectrum of H^3 β-Rays." Phys. Rev. (2), 60, 160(1941).

H^3 is β-radioactive with long half-life; the maximum β-ray energy is of the order of 10 kev. The total ionization, hence the energy, of a low energy β-particle can be measured with the Wilson cloud chamber, if individual droplets can be counted, and if the correlation between droplets formed and ions present is known. The drop-ion correlation and the average energy loss per ion pair were determined from a study of the droplet clusters produced in the chamber by 8.86-kev. x-ray photoelectrons. H^3 β-rays result in similar clusters. Count of the droplets gives the β-ray energy. 108 H^3 clusters photographed have a mean energy of 6.5 kev. For a Fermi distribution, the maximum energy is $^9/_5$ of the mean; $^9/_5$ of 6.5 kev. is 11.7 kev. In disagreement with this value, linear extrapolation from the observed distribution indicates a maximum of 14.5 kev; and several clusters of 13.5 kev were observed. It is believed that the maximum energy is 14.5 ± 1 kev.

95 O'Neal, R. D. "Note on the β-ray Energy of H^3." Phys. Rev. (2), 60, 359-60(1941).

The exptl. results of Brown and of O'Neal and Goldhaber are discussed. The max. energy of β-rays from H^3 is 15 ± 3 kev.

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96 Allen, M. B. and Ruben, S. "Tracer Studies with Radioactive Carbon and Hydrogen. The Synthesis and Oxidation of Fumaric Acid." J. Am. Chem. Soc. 64, 948-50(1942).

Oxidation of fumaric acid (I) with $KMnO_4$ in 1.5N H_2SO_4 at 35-50° gives 3 moles CO_2 and 1 of HCO_2H. To det. whether the HCO_2H originates from the methine or carboxyl C or both, radioactive C has been used as a tracer. Details are given of the synthesis of $(:CHC^*O_2H)_2$ (II), starting with $C^{11}O$ and passing through the steps of CO_2, KCN, $(CH_2CN)_2$ and (CH_2CO_2H), the dehydrogenation to II being carried out with a beef-heart prepn. rich in succinic dehydrogenase; the total time of the synthesis of II from the $C^{11}O$ was about 2 hrs. The HCO_2H from II gives an inactive carbonate and thus it originates from either of the 2 methine C and not from the CO_2H groups. Using H^3 it is shown that the exchange of H bound to C in I and HCO_2H with H ion is slow in acid and neutral soln. The H bonded to the methine C does not exchange with H ions during the oxidation of I to HCO_2H. The implications of these results are discussed and a tenta-

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tive mechanism is proposed, $HOCH(CO_2H)_2$ being considered an intermediate.

97 Borst, L. B. "Deuteron-Tritium Reaction in Nitrogen and Fluorine." Phys. Rev. (2), 61, 106(1942).

The deuteron-tritium reaction has been reported for several elements including H^2, Be^9, Cu^{63}, Ag^{107}, and Sb. The following reactions have been established in nitrogen and fluorine: $N^{14}(d,H^3)N^{13}$; $F^{19}(d,H^3)F^{18}$; Q = -4.5 ± 0.2 Mev; Q = -4.5±1.1 Mev. No such reactions have been found, however, in aluminum and phosphorus, using 8.2-Mev. deuterons. Excitation functions have been measured and the thresholds were found to be 6.8 ± 0.1 Mev. for nitrogen; 6.6 ± 0.2 Mev. for fluorine. The percentage of the barrier height at which H^3 particles may escape is estimated to be: 58 per cent for nitrogen; 66 per cent for fluorine; and 76 per cent for aluminum.

98 Feshbach, H. "The Theory of Hydrogen Three." Phys. Rev. (2), 61, 544(1942).

The effect of including tensor forces in the theory of H^3 has been considered. As is known, beside the $^2S_{\frac{1}{2}}$ state, the ground state also contains $^4D_{\frac{1}{2}}$, $^2P_{\frac{1}{2}}$, $^4P_{\frac{1}{2}}$ terms. There are two S states and three D states. Representations of all these have been found in Eulerian coordinates. With a technique similar to Rarita and Schwinger, representations have now been found in terms of operators acting on the most important $^2S_{\frac{1}{2}}$ state. The problem has been reduced to that of three coordinates in the plane of the three particles by integrating over the Eulerian angles, making use of these representations. This has been done for both exchange and non-exchange forces. The most important states turn out to be the S and D states which are anti-symmetric with respect to the exchange of two like particles, as far as their dependence on both spin and Eulerian angle is concerned. This work opens the way for an application of the James-Coolidge method to the problem.

99 Fontana, B. J. "Hydrogen Exchange of Aromatic Amines with D_2O and T_2O." J. Am. Chem. Soc. 64, 2503-4(1942).

Data are given for the exchange nos. and partition ratios of crystal violet, methylene blue, methyl orange, Congo red, benzidine and its mono- and di-HCl salts with H_2^2O and H_2^3O. Little or no exchange occurred in the dyes trypan blue and trypan red.

100 Gerjuoy, E. and Schwinger, J. "On Tensor Forces and the Theory of Light Nuclei." Phys. Rev. (2), 61, 138(1942).

The quadrupole moment of the deuteron indicates the existence of non-central tensor forces in nuclei which destroy the constancy of the total orbital angular momentum. With simple operational representations of the wave functions, the influence of two-body tensor forces on the ground state eigenfunctions of the light nuclei H^3 and He^4 has been calculated. In H^3, the tensor forces directly couple to the fundamental $^2S_{\frac{1}{2}}$ state a $^4D_{\frac{1}{2}}$ state, which in turn interacts with $^2P_{\frac{1}{2}}$ and $^4P_{\frac{1}{2}}$. To the fundamental $^1S_0$ state of He^4 is admixed a $^5D_0$ state which is coupled by the tensor forces with $^3P_0$. All states consistent with the total angular momentum and parity conservation rules, occur in the ground state eigenfunctions, and these nuclei therefore constitute the simplest examples of the complete breakdown of spin and orbital angular momentum conservation laws. Rarita and Schwinger have satisfactorily accounted for the properties of the deuteron by including the tensor force in a simple interaction represented by a rectangular well potential. With this interaction to describe the forces between all pairs of nuclear particles, the binding energies of H^3 and He^4 have been estimated by a variation method. The trial functions are of the form $^2S_{\frac{1}{2}}$ + $^4D_{\frac{1}{2}}$ for H^3 and $^1S_0$ + $^5D_0$ for He^4, with Gaussian radial functions. The calculations yield 32 and 50 per cent of the binding energy for H^3 and He^4, respectively, while a similar test calculation for the deuteron gives 54 per cent of the binding energy. The probability that these nuclei are in a D state is found to be 4 per cent for all three nuclei, in agreement with the exact deuteron computations. Improvement of the radial dependence of the trial functions increases the estimated binding energy of the deuteron to 76 per cent of the known value but does not materially affect either the estimated binding energy of H^3 and He^4, or the amount of D state admixture of the three nuclei. An analysis of the results shows that the tensor forces, which produce all the binding in the deuteron, are relatively ineffective in binding H^3 and He^4. This apparently indicates that the assumption of ordinary and tensor forces of the same range is not adequate to represent the properties of H^3 and He^4.

101 Harman, D., Stewart, T. D. and Ruben, S. "A Study of the Menschutkin Reaction, Using Radioactive Hydrogen as a Tracer." J. Am. Chem. Soc. 64, 2294-6 (1942).

Excess NMe_3 was quaternized by MeI in which the H atoms were in part replaced by tritium. All the radioactivity was found in the quaternary salt, none in the excess amine. The solvents used were alcohol and benzene. Incomplete quaternization of $PhNMe_2$ in alc. or benzene produced no radioactivity in the unreacted base. It is concluded that for these cases there is no reaction intermediate which is reversibly formed and in which iodide ion loses its identity with the Me group to which it was originally attached. NMe_4I or NMe_4Cl does not methylate NMe_3 in alc. at room temp. in 8 hrs.; in benzene suspension no reaction occurs in 3 days.

102 Harman, D., Stewart, T. D. and Ruben, S. "Tracer Studies with Radioactive Hydrogen. The Synthesis of Labeled Methyl Iodide." J. Am. Chem. Soc. 64, 2293-4(1942).

Radioactive MeI was prepd. by 2 processes, the one leading to a compd. contg. short-lived C^{11}, the other to a compd. contg. radioactive hydrogen. Each process is designed for small amts. of material.

103 Libby, W. F. and Barter, C. A. "Vapor Pressures of the Tritium Liquid Hydrogens. Dependence of Hydrogen Vapor Pressure on Mass of the Molecule." J. Chem. Phys. 10, 184-6(1942).

The Henry's-law consts. for HT ($T = H^3$) evapg. from approx. 10^{-9} M solns. in normal H_2 and for DT from nD_2 were detd. by distn. and measurement of the radioactivities of the distillate gases. Since Lewis and Hanson showed that H_2 and D_2 form nearly perfect solns., the Henry's-law consts. were assumed to represent the vapor pressures of the pure HT and DT liquids. From a plot of vapor pressures of various kinds of H at 20.4°K. the vapor pressure of liquid nT_2 at 20.4°K. is predicted to be 45 ± 10 mm. Hg.

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104 Norris, T. H., Ruben, S. and Allen, M. B. "Tracer Studies with Radioactive Hydrogen. Some Experiments on Photosynthesis and Chlorophyll." J. Am. Chem. Soc. 64, 3037-40(1942).

The research was undertaken on the assumption that using radioactive hydrogen, H^3, called T, as a tracer it might be possible to learn whether or not chlorophyll is participating in photosynthesis as a donor of hydrogen. If photosynthesis is allowed to proceed for a sufficiently long time in water contg. HTO chlorophyll contg. T should be formed if the idea underlying the reaction mechanism of the role of chlorophyll is correct. The results indicate that the formation of chlorophyll contg. T could not be detected during photosynthesis of Chlorellapyrenoidosa in HTO + H_2O. No (less than 5%) thermal exchange was observed between purified chlorophyll and 80% ethanol contg. HTO. The implications of these results for the theory that chlorophyll acts as a hydrogen donor in photosynthesis are discussed. It is pointed out that repetition of the expts. herein described using 100% D_2O would avoid the question of isotope sepn. and make possible an unequivocal conclusion regarding the role of chlorophyll.

105 Sachs, R. G. and Schwinger, J. "On the Magnetic Moments of H^3 and He^3." Phys. Rev. (2), 61(1942).

The magnetic moments of the light nuclei constitute a source of information concerning the extent to which spin conservation laws are relaxed in many-body systems. The sum of the moments of two nuclei which can be obtained from each other by an interchange of neutrons and protons has a particularly simple interpretation since it depends only on the amount of admixture of the possible LS states. Of this class of nuclei, H^3 and He^3 are of particular interest since the magnetic moments of both can presumably be measured. The theoretical value of the sum of their moments is $\mu H^3 + \mu He^3 = \mu n + \mu p - 2/3(\mu n + \mu p - \frac{1}{2})\ (3^4D + 2^2P - {}^4P)$, where the state symbols indicate the probability that the system be found in the corresponding state. It is likely that the ground states of these nuclei are predominantly ${}^2S + {}^4D$ and thus, if ${}^4D$ = 5 per cent, $\mu H^3 + \mu He^3 = 0.841$ nuclear magneton, which is to be contrasted with the deuteron moment (0.857), the expected theoretical value if L - S coupling holds rigorously. The moments of the individual nuclei depend on the detailed structure of the ${}^4D$ function but if a particularly simple form is assumed, then $\mu H^3 = \mu p - 2/3(2\mu p + \mu n - \frac{1}{2})^4D$, is found, whence $\mu H^3 = 2.68$ and $\mu He^3 = -1.84$.

1943

106 Baker, C. P., Holloway, M. G., King, L. D. P. and Schreiber, R. E. "The Cross Section for the Reaction D(T,α)n. Sept. 17, 1943. (AECD-2226; LADC-540).

This is a final report on the measurements made of the cross section for the reaction $H^2(H^3,\alpha)n$ for incident energies of tritons between 0.3 and 1.0 Mev. using a target about 0.2 Mev. thick. The measurements, made in a cone of approximately 30° about the direction of the beam, give a thick target cross section, which increases with increasing energy to a maximum value of 2.1 barns at 0.32 Mev. and decreases to a value of 0.6 barns at 0.9 Mev. Measurements made in a zone at right angles to the direction of the beam indicate a peak value of 2.8 barns also at 0.32 Mev. and a value of 0.7 barns at 0.9 Mev. These last values are subject to corrections for final calculations of the solid angles.

107 Black, J. F. and Taylor, H. S. "Equilibrium in H-Water Systems Containing Tritium." J. Chem. Phys. 11, 395-402(1943).

The equil. const. of the reaction HT + H_2O = H_2 + HTO involving radioactive H (T) was detd. (289-576°K) in contact with a Pt-charcoal catalyst. The results are summarized in the equations: (1) log K = 0.292 log T + (336.5/T) - 1.055; (2)ΔF^0 = 4.83T- 134T log T - 1540; (3) ΔH^0 = 0.58T - 1540; (4) ΔS^0 = 1.34 log T - 4.5; (5) ΔC_p = 0.58 ± 0.05 cal./deg./mole; (6) ΔH^0 = -1540 ± 160 cal./mole; (7) I = 1.055. Comparison of these exptl. results with theoretical calcns. by Libby indicates the correctness of the latter and confirms the assumption with respect to isotopic species that the forces acting within a mol. are unaltered by the change in nuclear mass and that any effects on the properties of the mol. are solely due to a different mass moving in the same force field.

108 Libby, W. F. "Vibrational Frequencies of the Isotopic Water Molecules; Equilibria with the Isotopic Hydrogens." J. Chem. Phys. 11, 101-9(1943).

The fundamental frequencies, anharmonicities and vibrational modes for the mols. HDO, HTO, DTO and T_2O are calcd. on the basis of Dennison's and Darling's recent analysis of the vibrational spectrum of the H_2O mol. The equil. consts. for 9 equilibria involving these mols. are given. Exptl. values for the reactions HD + H_2O = H_2 + HDO and HT + H_2O = H_2 + HTO are compared with those calcd. The vibrational potential function is essentially unaltered by isotopic substitution.

1945

109 Meitner, L. "Deuteron-Induced Radioactivities in Copper." Arkiv Mat. Astron. Fysik A33, no. 3, 12p. (1945).

Investigation of the radioactive isotope Cu^{63} (half-life 5.0 min.) which emits an intensive γ-radiation of 1.32 ± 0.04 Mev. The energy thresholds for the processes $Cu^{63}(d,H^3) \rightarrow Cu^{62}$; and $Cu^{63}(d,2n) \rightarrow Zn^{63}$ lie below 6.0 Mev., being probably 5.2 ± 0.4 Mev. for the first one, and 5.5 ± 0.4 Mev. for the second one.

110 Powell, T. M. and Reid, E. B. "Investigation of the Mechanism of Butane Isomerization using Radioactive Hydrogen as a Tracer." J. Am. Chem. Soc. 67, 1020-6(1945).

With the radioactive hydrogen isotope, H^3 (abbreviated as T), as a tracer, an attempt was made to det. the steps involved in the reaction, butane $\rightleftarrows$ isobutane, performed over $AlCl_3$ on Al_2O_3, and charcoal supports. The results of tritium exchange between H, HCl, and butanes during isomerization are presented. These show that exchange of tritium in HCl to butane is large compared to exchange of tritium in H(HT) to butane.

1946

111 Bretscher, E. and French, A. P. Low Energy Cross Section of the D-D Reaction and Angular Distribution

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of the Protons Emitted. Sept. 17, 1946. (AECD-2570; LADC-240).

The thick-target yield of the reaction $H^2 + H^2 \rightarrow H^3 + p +$ 3.98 Mev. has been measured, using a heavy-ice target, and observations have been made on the angular distribution of the protons. Experiments have been carried out in the region 15 kev. to 105 kev. incident deuteron energy. Evidence has been obtained that, even for very small bombarding energies, the angular distribution of protons in the center-of-gravity (c.g.) system does not become isotropic. The variation of the cross section with energy can only approximately be represented by a Gamow function.

112 Colby, M. Y. and Little, R. N., Jr. "Possible Results of a New Reaction." Phys. Rev. (2), 70, 437 (1946).

Possible reactions between H^3 and H^2 are discussed.

113 Graves, A. C., Graves, E. R., Coon, J. H. and Manley, J. H. "Cross Section of $D(d,p)H^3$ Reaction." Phys. Rev. (2), 70, 101(1946). (MDDC-207).

The total proton yield from a thick heavy ice target has been measured for four bombarding voltages between 100 and 300 kev. by counting protons emerging from the target chamber at three angles. The results are summarized in Table I.

Table I

Neutron energy kev.	Thick target yield protons/deuterons x 10^7	Cross section (10^{-26} cm^2)
122	0.78	2.6
171	1.7	3.3
219	3.0	3.9
300	5.5	5.2

114 Henriques, F. C., Jr. and Margnetti, C. "Analytical Procedure for Measurement of Radioactive Hydrogen (Tritium)." Ind. Eng. Chem., Anal., Ed. 18, 420-2 (1946).

A procedure for the routine detn. of tritium depends on insertion of H gas in a quartz ionization chamber attached to a Lauritzen electroscope. Details are given for collection of H_2O from combustion of samples, and for its conversion to H for measurement. The sensitivity is reported to be about 10^{-4} microcurie of H^3 per 10 millimoles of H, with analysis to 2% shown on all samples having activity greater than background

115 Sachs, R. G. and Schwinger, J. "The Magnetic Moments of H^3 and He^3." Phys. Rev. (2), 70.41-3 (1946).

A measurement of the magnetic moments of the nuclei H^3 and He^3 would yield information concerning the deviations from L-S coupling in these nuclei. It is shown that the sum of the moments of the two nuclei can be directly related to the amount of admixture of the ^2P, ^4P, and ^4D eigenfunctions with the ^2S function. Thus the measurement of both moments would lead to direct information concerning the contributions of these functions to the ground state of the two nuclei. The individual moments depend to some extent on the detailed properties of the wave functions, but if only the ^2S and ^4D

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functions contribute appreciably to the ground state, and if particularly simple forms of these functions are assumed, the moment of each nucleus is shown to be expressible in terms of the amount of admixture of the two functions. If then the amount of ^4D function is taken to be 4 per cent on the basis of an estimate by Gerjuoy and Schwinger, the moments of H^3 and He^3 are found to be 2.71 and -1.86 nuclear magnetons, respectively.

116 Stewart, T. D. and Harman, D. "Exchange of Hydrogen and Tritium Ions during Alkylation, Catalyzed by Tritium Sulfuric Acid." J. Am. Chem. Soc. 68, 1135-6(1946).

The reaction of 0.48 mole of isobutane and 0.109 mole of 2-butene, added under pressure during 15 min. to 0.131 mole of 100% T_2SO_4 (sp. activity 5.43 x 10^7) at 10°, gave an alkylate, 10% of which b. 99-100°, 10% at 114-16°, and 60% residue, in which the activity of the H was practically the same; the sp. activity corresponds closely to the assumption of a random distribution of all the H and T atoms in the 2 reactants, prior to alkylation. When 40 ml. isobutane and 6 ml. T_2SO_4 were stirred at 10° for 20 min. the sp. activity of the H is 1.36 x 10^5, corresponding to 7.1% of random distribution of the H atoms of the catalyst and the tertiary H atoms of the isobutane. When 2-isobutane is bubbled through T_2SO_4 the activity of the H is 6.1/10^5; this demonstrates a rapid exchange and also a reversible absorption of the alkene in T_2SO_4.

117 Wang, M. "A Calculation of the Binding Energies of H^3 and He^4 with a New Potential." Phys. Rev. (2), 70, 492-4(1946).

The binding energies of the muclei H^3 and H^4 are calcd. to be 7.3 and 15.1 Mev., resp., by the method of equiv. two-body, with the potential previously suggested. The range at which the potential between two nucleons is cut off is the same as that for the case of the deuteron, and the same range for the equiv. two-body is deduced accordingly.

118 Watts, R. J. and Williams, D. "Beta-Rays from H^3." Phys. Rev. (2), 70, 640-2(1946). (MDDC-141; LADC-100).

The upper limit of the β-ray spectrum of H^3 has been redetermined by a method involving the passage of β-particles through a thin window into a Geiger counter, aided by an adjustable accelerating field. The effective window thickness was determined by acceleration of electrons from a hot filament. The value obtained for the upper limit is 11 ± 2 kev.

119 Wiedenbeck, M. L. "Radioactive Isotopes in the Columbium Region." Phys. Rev. (2), 70, 435(1946).

Short bombardments of Cb metal foil with 10-Mev. deuterons produced the 6.6-min. β-activity in Cb^{94}, and the 18-min. and 6.5-hr. positron activities, owing to isomeric states of Mo^{93}, from $Cb^{93}(d,2n)Mo^{93}$. Prolonged irradiation of Cb metal foil produced intense short-lived activity. After all up to 6.5-hr. Mo^{93} had decreased to a negligible value, activities of 21.6-hrs. and 11 days were found. The 21.6-hr. activity is due to an isomeric state of Cb^{92}, from $Cb^{93}(d,H^3)$ Cb^{92}; it emits β- with an upper limit of 1.2 Mev., and γ-rays of 0.6 Mev. The 11-day isotope is also due to Cb^{92} from $Cb^{93}(d,H^3)Cb^{92}$. The threshold for both these activities is 5-6 Mev.

1947

120 Anderson, H. L. and Novick, A. "Magnetic Moment of the Triton." Phys. Rev. (2), 71, 372-3(1947). (MDDC-617).

The ratio of the nuclear g value of the triton to that of the proton is 1.0666 ± 0.00010. The detn. was made by the method of nuclear induction.

121 Bloch, F., Graves, A. C., Packard, M. and Spence, R. W. "Relative Moments of H^1 and H^3." Phys. Rev. (2), 71, 551(1947).

The value of magnetic moment, μ, for H^3 (μ_T) is reported to be

$$\mu_T = (1.066636 \pm 0.00001)\ \mu_P$$

where μ_P is the corresponding value for H^1. Experiments (38) carried out at B_0 values of 9300 and 9900 Gauss.

122 Bloch, F., Graves, A. C., Packard, M. and Spence, R. W. "Spin and Magnetic Moment of Tritium." Phys. Rev. (2), 71, 373-4(1947). (MDDC-618; LADC-339).

By use of the method of nuclear induction, it was found that the triton has a spin of 1/2 and its magnetic moment is positive and 1.067 ± 0.001 times larger than that of the proton.

123 Branson, H. "Use of Isotopes to Determine the Rate of a Biochemical Reaction." Science 106, 404 (1947).

Radioactive and stable pairs such as (H^2, H^3), (C^{13}, C^{14}), (S^{34}, S^{35}) and radioactive pair (Fe^{55}, Fe^{59}) can be used for these elements. No radioactive member exists for O or N, but they can be coupled with H, C or S. The assays require simultaneous use of the mass spectrometer and the Geiger-Müller counter.

124 Butler, G. C. "Tracers in Biology." Proc. Conf. Nuclear Chem., Chem. Inst. Can. 159-66(1947).

The use of isotopes, not commonly found in nature in high concns., as tracers in biol. and biochem. research is reviewed and the limitations of the various techniques are given. The isotopes which are of greatest use in biol. and medical research are: H^2; H^3; C^{11}; C^{12}; C^{14}; N^{15}; S^{34}; S^{35}; P^{32}; O^{18}; Na^{24}; Cl^{38}; K^{42}; Ca^{45}; Fe^{55}; Fe^{59}; and I^{131}. Isotopes of C, H, and N have found their greatest use in the study of intermediary metabolism; the last 7 are used in tracing inorg. mols. while isotopes of S and P, and to a lesser extent those of O and I, are used for studying the metabolism of both org. and inorg. mols.

125 Coon, J. H., Goldblatt, M., Nobles, R. and Robinson, C. F. The Reaction $He^3(n,p)H^3$ Induced by Thermal Neutrons. Los Alamos Scientific Laboratory. Dec. 8, 1947. (AECD-2190; LADC-462).

Measurement of cross section for $He^3 + n = H^3 + H^1 + 0.75$ Mev. measured by counting ionization pulses from products. The cross section of the reaction is reported to be 7400 (±20%) x 10^{-24} cm^2. A graph of pulse height vs. counts for N and He^3 is given.

126 Eidinoff, M. L. "Cathodic Protium-Tritium Separation Factor." J. Am. Chem. Soc. 69, 977(1947).

Protium-tritium spn. factors of $13._4$ and $14._7$ were observed in the electrolysis at 20° of 10% MaOH at a smooth Pt foil cathode with a c.d. of 0.1 amp./sq. cm., approx. 2 x 10^{-3} mole of H being produced. The alk. soln. contained approx. 10^{-11} atom fraction tritium and had a normal D content. The protium-tritium ratio for the H gas in the electrolysis is slightly more than twice that corresponding to thermodynamic equil. of the electrode interface. The method of measuring tritium activity is reported.

127 Eidinoff, M. L. "The Quantitative Measurement of Tritium: Hydrogen-Alcohol-Argon Mixtures." J. Am. Chem. Soc. 69, 2504-7(1947).

Gas-counting mixts. contg. H, EtOH, and A, each at a partial pressure of approx. 25 mm. Hg furnished a counting rate proportional to the tritium concn. Average deviations found in tests of counting-rate reproducibility are less than 1% for activities ten times background. The Geiger-Müller counter tube contained a Cu-gauze cathode and a 4-mil W anode inside a 45-mm. (outside-diam.) glass envelope. A plateau of 20-40 v. starts about 50 v. above the threshold of 1250 v. Gas lines and bank of counter tubes are shown.

128 Eidinoff, M. L. "Upper Limit to the Tritium Content of Ordinary Water." J. Chem. Phys. 15, 416 (1947).

The upper limit is less than 1 part in 10^{17} parts.

129 Fröhlich, H. and Huang, K. "The Binding Energies of Very Light Nuclei." Proc. Roy. Soc. A191, 61-82 (1947).

The static interaction of the Møller-Rosenfeld theory is used to calc. approx. the binding energies of the nuclei H^2, H^3, He^3, and He^4. The value of the meson mass and of the two other parameters available in the theory are detd. from a comparison with the observed binding energies of the H^3 nucleus and of the singlet and triplet states of the deuteron. The meson mass so detd. is between 210 and 220 electron masses, which is in fair agreement with cosmic-ray measurements. The binding energy of He^3 calcd. from the energy difference, H^3-He^3, is also found to be in fair agreement with the observed value. The theoretical binding energy of He is less than half the observed value; it is suggested that in this nucleus there exists an addnl. many-body interaction. The calcd. Coulomb energy of the He nucleus is about 10-20% higher than that deduced from expt.; this may also be considered as satisfactory agreement. The calcns. do not lead to any disagreement with expts. on H^2, H^3, and He^3. They suggest that the binding energies of H^2, H^3, and He^3 but not that of He^4 can be accounted for by the static interaction; they also indicate the existence of many-body forces which would be of importance for He^4 and for heavier nuclei.

130 Fröhlich, H., Ramsey, W. H. and Sneddon, I. N. "A Quantitative Discussion of the Interaction Between Nuclear Particles." International Conference on Fundamental Particles and Low Temperatures. London, Physical Society. 1947. Vol. I, 166-75.

The static Møller-Rosenfeld theory is used to calculate the binding energies of H^2, H^3, He^3, and He^4, as well as the angular distribution of neutron-proton scattering. The three parameters available in the theory (one of them is the meson mass) are obtained from a comparison with the experimental binding energies of the H^2 (singlet and triplet) and H^3 nuclei. The meson mass, m, is found to be 225 electron masses,

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which is in agreement with the existing experimental data which are centered near m = 200. The energy difference between He^3 and H^3 is also found to be in good agreement with the experimental value. For He^4 the theoretical binding energy is less than half of the experimental value. It is shown, however, that an additional attractive force amounting to about 15% of the static force would lead to the correct binding energy. It is found that this could not be obtained by slight ($\sim$15%) change in the values of the parameters, and it is suggested that such a force might indicate the existence of many-body forces which would be more important for He^4 than for H^3. The angular dependence of the neutron-proton scattering is found to agree with the experiments by Occhialini and Powell (1946), but the accuracy of the experiments does not, at present, permit a final conclusion about the validity of the theory.

131 Goldblatt, M., Robinson, E. S. and Spence, R. W. "The Half-Life of Tritium." Phys. Rev. (2), 72, 973(1947). (AECD-2585; MDDC-1229; LADC-421).

The decrease with time in an ion current from an ion chamber contg. a mixt. of H and H^3 was measured for 18 days; from these data the half-life of H^3 was found to be 10.7 ± 2.0 yrs.

132 Goldstein, L. On the Inverse Reactions $H^3(p,n)He^3$ and $He^3(n,p)H^3$. Dec. 16, 1947, (AECD-2222; LADC-539).

It is shown that these two reversible reactions, at corresponding energies, may be of particular interest in the experimental verifications of the general quantum mechanical cross-section ratio formula,

$$\frac{\sigma_{if}}{\sigma_{fr}} = \frac{p_f^2}{p_i^2}$$

p_f and p_i denoting the relative linear momenta of the particles produced in the i → f and f → i reactions, respectively. In the present case,

$$\frac{\sigma[H^3(p,n)He^3]}{\sigma[He^3(n,p)H^3]} = \frac{p_n^2}{p_p^2}$$

p_n and p_p being the relative linear momenta of the neutron and proton produced in these reactions, at corresponding energies. Some of the properties of the highly excited He^4 nuclei likely to be involved in these reactions are described. It is shown that capture of slow protons and slow neutrons is in principle possible by the H^3 and He^3 nuclei and should be looked for by means of the gamma radiation which should accompany these capture processes. The large thermal neutron cross-section of the $He^3(n,p)H^3$ process observed recently in some preliminary experiments seems to constitute a qualitative verification of the preceding cross-section ratio formula.

133 Gurin, S. and Delluva, A. M. "The Biological Synthesis of Radioactive Adrenaline from Phenylalanine." J. Biol. Chem. 170, 545-50(1947).

When DL-$PhCH_2C^{14}HNH_2C^{14}O_2H$ was fed to rats, 3,4-$(OH)_2C_6H_3CHOHC^{14}H_2NHMe$ was recovered from exts. of the adrenals. DL-Phenylalanine labeled with tritium is also converted to adrenaline.

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134 Konopinski, E. J. "H^3 and the Mass of the Neutrino." Phys. Rev. (2), 72, 518-19(1947).

The max. energy of the β-particles from H^3 is 11 ± 2 kev. The unusually low energy of this β-spectrum makes it extremely sensitive as an indicator of a nonvanishing rest mass for the neutrino. Coupled with measurements of the H^3 half-life, it shows that the neutrino cannot have a mass greater than 2.3% of the rest mass of the electron. Moreover, the H^3 decay rate as presently known seems 6-10 times too rapid in comparison with that of heavier elements unless the neutrino has a finite mass of the magnitude mentioned.

135 Kundu, D. N. and Pool, M. L. "d-H^3 Reaction in Cb and Ag." Phys. Rev. 71, 140(1947).

With heavy nuclei, d-H^3 reactions had been reported in Ag and Cu, but the possibility of spurious n-2n reactions with neutrons from d+d reactions, neutrons produced within the target material, chamber background neutrons was not completely ruled out. In the following, a number of thin foils of spectro-chemically tested Cb of the same area and thickness, and shielded on all sides except the front, were bombarded with 10 Mev. deuterons for various lengths of time. The foils were of such a thickness (0.005") that the deuterons were completely stopped by the first foil; the other foils were subjected to neutron reactions only, if any. The Cb^{92} (10.1 D) activity was found, with and without chemistry, in good strength in the first foil; there was no measurable activity of this half-life in the other foils. The decay curves (10.1 D), β^-(1.38 Mev.), γ(1.0 Mev.), and ZrK_α x-rays (0.78A) decaying with 10.1 D checked well with Cb^{92}. With the deuteron energy used, the d-(p,2n) and d-(d,n) reactions being less probable, the reaction is mostly $Cb^{93}(d,H^3)Cb^{92}$. With Ag target the same method gave Ag^{106} (24.5 min.) due to d-H^3 reaction.

136 Kundu, D. N. and Pool, M. L. "Results of H^3 Bombardment of Ag Leading to Pd^{109}." Phys. Rev. (2), 72, 101-8(1947).

H^3 was produced by (d,H^3) reaction in Be and Ag and immediately utilized as are neutrons in a fast-neutron bombardment. The energy of the H^3 particles was about 10 Mev. The target was a stack of Ag foils, in front of which different thicknesses of Be were placed, and a 10-Mev. deuteron beam was made to impinge on the Be. The H^3 generated within Be produced the 13-hr. Pd^{109} activity in Ag foils, as confirmed by chemistry. The reaction is believed to be $Ag^{109}(H^3,He^3)Pd^{109}$. Spurious (n,p) reaction was estd. and corrected for. The observed range of H^3 in different materials is discussed. The threshold for the H^3 reaction in Ag is roughly estd. to be between 1.1 and 1.5 Mev.

137 Kundu, D. N. and Pool, M. L. "Results of H^3 Bombardments on Ag and Rh." Phys. Rev. (2), 71, 467 (1947).

H^3 has been used as the bombarding particle to effect nuclear reactions. The 13-hour Pd^{109} activity has been produced by bombarding silver with H^3 according to the reaction $Ag^{109}(H^3, He^3)Pd^{109}$. The assignment of this activity to Pd^{109} and not to Pd^{107} has been further checked by observing that this activity is not produced on prolonged alpha bombardment of Ru. The possibility of a (d,α) reaction leading to any confusion as to results has been obviated. The effect of the reaction

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$Ag^{109}(n,p)Pd^{109}$ has been estimated and corrected for. There is reason to believe that the reaction (H^3,p) also takes place. The 7.5-day Ag^{111} activity appears to be produced because of $Ag^{109}(H^3, p)Ag^{111}$ and also with a much longer bombardment, the reaction $Rh^{103}(H^3,p)Rh^{105}$ seems to be evident, resulting in the 35-hour Rh^{105} activity. The energy of the H^3 particles used is approximately 10 Mev.

138 Libby, W. F. "Measurement of Radioactive Tracers, Particularly C^{14}, S^{35}, T, and Other Long-lived Low-energy Activities." Anal. Chem. 19, 2-6(1947).

The tremendous relative importance of scattering in the weakening of soft β-radiation necessitates an empirical approach somewhat different from that used for hard radiation. The counting rate of a soft β-sample thicker than the range of the radiation will be 10% of the total disintegration rate. If a given amt. of activity in an infinitely thin layer gives an intensity I_0, the intensity I obtained as this same amt. of activity is dild. and the sample layer thus thickened is $I/I_{00} = 1/5x$, where x is sample thickness/range. (Valid when x is more than 1.) For the above isotopes, the ranges are 20, 15, and 0.23 mg./sq. cm., resp. If sp. activity is const. the intensity I from a layer of thickness x, referred to the intensity I_{00} from an infinitely thick layer, is $I/I_{00} = 1 - e^{-5x}$. The min. no. of counts E for 10% (standard deviation) accuracy in 10-min. measurement is given by $E = 10[1 + (2L^2/5\alpha)^{1/2}]$ where L is the length and L/α the diam. of the counter. End-window, screen-wall and ordinary type gas-filled counter characteristics are described.

139 Lyubarskiĭ, G. D. "The Radioactive Isotopes of Hydrogen (Tritium) and Its Use as an Indicator of Chemical Reactions." Uspekhi Khim. 16, No. 4 (1947).

A review with 70 references. Covers discovery, isolation, production, and properties of H^3. Data on energy of β-rays; H^1H^3, H^2H^3, and H_2^3 vapor pressures; equilibrium for H_2O containing H^1 ahd H^3; and analytical methods are included. Presents discussions on the use of H^3 as a tracer in examining oxidation of fumaric acid, Menshutkin Reaction, exchange in amines, role of chlorophyll in photosynthesis, alkylation in liquid phase, and isomerism of butanes and butylene.

140 Novick, A. "Half-life of Tritium." Phys. Rev. (2), 72, 972(1947). (MDDC-1236).

By collecting and measuring the amt. of He^3 produced by the β-decay of H^3 over a max. period of 197 days, the half-life of H^3 was found to be 12.1 ± 0.5 yrs.

141 Pace, N., Kline, L., Schachman, H. K. and Harfenist, M. "Studies on Body Composition. IV. Use of Radioactive Hydrogen for Measurement in Vivo of Total Body Water." J. Biol. Chem. 168, 459-69 (1947). (NP-597).

The problem of in vivo determination of total body water in man was approached using the radioactive isotope of hydrogen (tritium) in the form of water (H^1H^3O). The tritium was obtained by cyclotron bombardment of beryllium and was then converted to water. A method was developed for the determination of the activity of this water. This involved modification of the Geiger-Müller counter tube so as to permit introduction into the tube of measured amounts of radioactive water vapor, alcohol and argon. It was possible to evacuate and rinse the tube before each determination. Water of known activity was injected into two rabbits and one man and the plasma activity determined after a period of equilibration. Comparison of results with calculated volume is made.

142 Rarita, W. "Tensor Forces and the Binding Energy of the Triton." Phys. Rev. (2), 73, 1272(1947).

Title of a paper presented before the Am. Phys. Soc. and published in abstract form.

143 Ringuet, L. L. "Complete Disintegration of the Silver Nucleus by Cosmic Rays." Atomes 3, 96-7 (1947).

Recently developed photographic emulsions have made possible new studies on the effect of cosmic radiation. A 34 branched star has been observed from the disintegration of silver nucleus by cosmic rays. These branches have been attributed to protons, tritons, and α-particles resulting from the disintegration of a silver nucleus.

144 Sachs, R. G. "Interpretation of the Triton Moment." Phys. Rev. (2), 72, 312-20(1947). (MDDC-866).

In order to account for the measured magnetic moment of the triton it is necessary to assume that the wave function in the ground state is a linear combination of ^2S, ^2P, ^4P, and ^4D functions. An attempt is made to det. the amplitudes of these functions from the magnetic moment or the assumption that the intrinsic nucleon moments are additive and that relativistic efforts are negligible. With certain reasonable assumptions concerning the nature of the wave functions, it is found that the relative probabilities for finding the system in the ^2P, ^4P, and ^4D states satisfy the relation shown by curves of $^2P^2(\%)$ vs. $D^2(\%)$. Wherever the results would otherwise be arbitrary, the wave functions have been chosen so as to minimize the amt. of P state, with the exception that only the lowest one-particle configurations have been considered. If the amplitude of the ^2S state is taken to be as large as possible, the wave function contains no ^4D state, 8% ^4P state, and 17% ^2P state. A wave function of this form would seem to indicate that there is a spin-orbit coupling other than the tensor interaction acting among nuclear particles. In the other extreme case that the wave function contains a max. of the ^4D function, the ^2S state probability is zero, the ^4D probability is 22%, the ^4P is 30%, and the ^2P is 48%. Curves of $-\mu He/\mu P$ vs. $D^2(\%)$ are drawn for He^3, on the assumption that the wave function of He^3 has the same form as that of H^3.

145 Seaborg, G. T. "Artificial Radioactive Tracers. Applications to Chemistry and Medicine." Science 105, 349-54(1947).

This review summarizes the prepn. and study of isotopes of elements nonexistent in nature: atomic nos. 43, 61, 85, 87, 93, 94, 95, and 96. It discusses exchange reactions and applications of H^3, C^{14}, Na^{24}, P^{32}, S^{35}, Ca^{45}, Fe^{59}, Zn^{65}, Sr^{89}, and I^{131}. It reviews studies in photosynthesis, animal metabolism, and other biochem. problems and mentions the therapeutic possibilities of active isotopes.

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146 Shapiro, M. M. and Barnes, J. R. The Application of $Li^6(n,\alpha)$ and $B^{10}(n,\alpha)$ to Slow Neutron Monitoring Clinton National Laboratory. Aug. 20, 1947. (MDDC-1471).

Description of the use of H^3 production in Li^6 loaded emulsions for neutron monitoring purposes. This paper is an abstract.

147 Villars, F. "The Magnetic Exchange Moment for H^3 and He^3." Phys. Rev. (2), 72, 256-7(1947).

The magnetic moment of H^3 is calcd. to be $\mu(H^3) = 2.975 = \mu(p) + 0.186$ nuclear magnetons; of He^3, $\mu \cong \mu(N) - M \cong -2.1$ nuclear magnetons.

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148 Aivazov, B. V. and Neiman, M. B. "Tritium, the Radioactive Isotope of Hydrogen." Uspekhi Fiz. Nauk 36, 145-80(1948).

A general survey of literature on H^3 is given covering such subjects as the history of its discovery and the methods of its isolation, its half-life and the energy of its β-radiation, the physical, chemical, and nuclear constants relative to H^3, the analytical methods for its determination, its applications as an indicator in chemistry and biology. 11 tables, 7 curves, 7 diagrams of instruments, 137 references.

149 Anderson, H. L. "Magnetic Exchange Moment for He^3 and H^3." Phys. Rev. (2), 73, 919-20(1948).

The exptl. values of the nuclear magnetic moments μ are: μ proton, +2.7928; μ neutron, -1.9125; μH^3, +2.9791; μHe^3, (-)2.131 ± 0.020. The large moments which are observed for H^3 and He^3 could be accounted for without exchange by assuming that the admixt. for the ground state is ${}^2P^2 = 0.383$, ${}^4P^2 = 0.617$, ${}^2S^2 = {}^4D^2 = 0$. It is more reasonable to accept Villars' explanation that the excess magnetic moment is caused by exchange currents and to accept the Gerjuoy-Schwinger admixt., which takes ${}^4P = {}^2P = 0$, and gives ${}^4D^2 = 0.042 \pm 0.026$.

150 Avery, R. and Sachs, R. G. "Further Remarks on the Magnetic Moments of H^3 and He^3." Phys. Rev. (2), 74, 1320-2(1948).

Arguments for the existence of exchange moments in the H^3 and He^3 nuclei depend on an accurate evaluation of the spin and orbital contributions to the moments. Assumptions made in previous evaluations are re-examined. Although the results do not establish the existence of the exchange moment conclusively, arguments are presented which make the alternative appear to be less reasonable. Methods for obtaining further information on this question are discussed.

151 Baskinski, A. "The Heaviest Hydrogen Isotope." Wiadomośći Chem. 2, 127-34(1948).

A review with 57 references.

152 Batchelor, R., Eppstein, J. S., Flowers, B. H. and Whittaker, A. Slow Neutron Capture in Helium. Atomic Energy Research Establishment. n.d. (AERE-N/R-278).

The cross section for the reaction $He^3(n,p)H^3$ with thermal neutrons has been measured in atmospheric helium by means of a pulse-ionization chamber technique in which the disintegrations produced in the chamber are counted and the rate compared to the disintegration rate in argon containing a small admixture of nitrogen, in the same chamber and under identical conditions. The result obtained is 3,700 x 10^{-24} cm^2 relative to the reaction $N^{14}(n,p)C^{14}$.

153 Blair, J. M., Freier, G., Lampi, E., Sleator, W. and Williams, J. H. "The Angular Distributions of the Products of the D - D Reaction: 1 to 3.5 Mev." Phys. Rev. (2), 74, 1599(1948).

Cross sections per unit solid angle for the reactions $H^2 + H^2 \rightarrow He^3 + n$ and $H^2 + H^2 \rightarrow H^1 + H^3$ have been measured at various angles for incident deuterons of energies from 1 to 3.5 Mev. The dependence of the cross sections on angle is nearly the same for the two reactions, and it can be represented by an expression of the form $A(1 + B\cos^2\phi + C\cos^4\phi)$, where ϕ is the angle of observation in the center of mass coordinate system. A increases from 4 x 10^{-27} cm^2 at 1 Mev. to 6 x 10^{-27} cm^2 at 3.5 Mev.; B decreases from approximately 1 at 1 Mev. to -3.5 at 3.5 Mev.; C increases from 1.5 at 1 Mev. to 7 at 3.5 Mev. The total cross sections for the two reactions are approximately constant at 10^{-25} cm^2 throughout this energy range.

154 Bretscher, E., French, A. P. and Seidl, F. G. P. "Low Energy Yield of $D(d,p)H^3$ and the Angular Distribution of the Emitted Protons." Phys. Rev. (2), 73, 815-21(1948). (MDDC-1348).

The thick target yield N(E) of the reaction $H^2 + H^2 \rightarrow H^3 + H^1 + 4.0$ Mev. was studied, with deuterons of 15-105 kev. energy on a heavy-ice target. Even for very small bombarding energies the angular distribution of protons in the c.g. system does not become isotropic. Evaluation of the cross sections $\sigma(E)$ from N(E) involves an estimate of the energy loss of deuterons in heavy ice. The variation of cross section $\sigma(E)$ with energy E is only approx. represented by a Gamow function.

155 Byatt, W. J., Rogers, F. T., Jr., and Waltner, A. "Cloud-Chamber Observations of the Decay of Tritium." Phys. Rev. (2), 74, 699(1948).

Beta-particle tracks from the decay of H^3 were observed in a cloud chamber; 1565 tracks were acceptable and the differential distribution of the projection length is shown. The maximum observed track length was 4.12 mm (referred to dry air at 15°C and 760 mm), which yields an energy of 11 ± 1 kev. as the corresponding maximum energy for the tritium beta particles.

156 Chastel, R. "Use of the Photographic Plate in Nuclear Physics." Atomes 3, 191-4(1948).

Use of the photographic plate enabled Becquerel to discover radioactivity. Visible traces in a photographic emulsion can be obtained from alpha particles as well as from other charged heavy particles, such as protons, deuterons and tritons. Photographic plates have permitted the experimental observation of the modes of fission of the uranium nucleus such as tripartition and quadripartition, and have been used in the observation of nuclear explosions produced by cosmic rays.

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157 Coon, J. H. "He^3 Isotopic Abundance Measurement by Counter Technique." Los Alamos Scientific Laboratory. June 9, 1948. (AECD-2207; LADC-532).

Analysis of He^3 concentrations is of importance because of the interest in He^3 for nuclear investigations in the light element region. In the present work, measurements were made of the isotopic abundance of He^3 in two samples of natural helium, one from wells near Amarillo, Texas, and one from air reduction processing. The method of measurement is applicable to analysis of the He^3 content of enriched samples prepared by thermal diffusion methods or by the production of He^3 through the decay of H^3. Briefly it consists of detecting the $He^3(n,p)H^3$ disintegrations induced by thermal neutrons. The helium gas is put into a proportional counter, the disintegration rate compared to that with nitrogen in the counter, and the He^3 content deduced by using the known ratio of the He^3 and N disintegration cross section.

158 Curran, S. C., Angus, J. and Cockroft, A. L. "Beta Spectrum of Tritium." Nature 162, 302-3(1948).

A new technique for rapid and accurate detection and energy measurement of β rays, conversion electrons, γ rays and x rays from weak sources has been developed. It is applicable to radiations of energy 0.5 - 150 kev., and uses a proportional counter connected to a high-gain linear amplifier. The β-spectrum for H^3 over the range 1 - 18 kev. is given. A maximum, which is wider than the theoretical curve maximum, is observed at 2.5 kev. The upper limit is 16.9 ± 0.3 kev. The application of the neutrino theory to the upper end of the spectrum seems justified, and a neutrino mass of less than m/300 is indicated.

159 Eidinoff, M. L. "The Search for Tritium - the Hydrogen Isotope of Mass Three." J. Chem. Education 25, 31-4, 40(1948).

History of search with notes on detection and properties. Review is well documented with 24 references.

160 Faraggi, H. "Application of the Method of Effacing the Latent Image and the Study of the Nuclear Reactions." Compt. rend. 227, 527-8(1948).

The method is described and applied to the traces of He^4 and H^3 formed in the reaction $Li^6(n,\alpha)H^3$. Direct development of an exposed plate shows a single uniform line, while a partial effacing of the latent image shows a broken line. On analysis, the trajectories are found to consist of two fragments. The results show a range of 8.2 ± 0.2 μ for He^4 and an energy of 2.0 ± 0.15 Mev. while H^3 has a range of 34.8 ± 0.2 μ and an energy of 2.70 ± 0.15 Mev.

161 Ghormley, J. A. and Allen, A. O. Decomposition of Tritium Oxide Under Its Own Radiation. Oak Ridge National Laboratory. Sept. 1, 1948. (ORNL-128).

Water in which 2 to 19% of the hydrogen is replaced by H^3 decomposes into H and O as a result of bombardment by the H^3 β-rays. The decomposition stops as a result of back reaction when the pressure of gaseous products reaches values which vary from 20 to 600 or more cm. Hg, depending apparently on the nature and amount of impurities present. The steady-state pressure of electrolytic gas is generally lowered by increase of temperature (to an extent varying for different samples) and by exposure to γ rays. The decomposition continues when the water is frozen and kept at liquid N temperature. He^3 formed by H^3 decay diffuses through the walls of fused silica vessels, but not through soft glass; and the activity of a tritium oxide sample can readily be determined by collecting and measuring the pure He which comes out through the walls of a silica container.

162 Goeppert-Mayer, M. and Sachs, R. G. "The Binding Energy of the Triton." Phys. Rev. (2), 73, 184-5 (1948).

Math.-theoretical.

163 Hughes, D. J. and Eggler, C. "The Reaction $He^3(n,p)H^3$ and the Neutrino Mass." Phys. Rev. (2), 73, 809-10(1948). (MDDC-1516).

The mass of the neutrino emitted in the disintegration of H^3 and C^{14} was detd. by a cloud-chamber detn. of the Q value for the reactions $He^3(n,p)H^3$ and $N^{14}(n,p)C^{14}$. The neutrino mass in each case involves only the n,p mass difference, the actual β-end point (not the Kurie extrapolated end point), and the Q value. The C^{14} and the H^3 neutrino have the same mass within 5 kev.; this excludes Oppenheimer's suggestion that nuclei of the H^3 type might emit neutrons of finite mass while the long-lived C^{14} might emit a massless neutrino. The abs. value of the neutrino mass is 0 ± 25 kev. The H^3 neutrino mass is definitely less than that needed to obtain conformity of the energy and lifetime with β-theory. If the discrepancy is ascribed to the end-point energy, assuming a massless neutrino, it would necessitate an error of more than a factor of two in the 11 kev. value.

164 Jones, W. M. Thermodynamic Functions for Tritium Deuteride. The Dissociation of Tritium Deuteride. Equilibria among the Isotopic Hydrogen Molecules. Oct. 27, 1948. (AECD-2427; LADC-589).

The heat capacity, entropy, internal energy and free energy are calculated to 2500°K for H^2H^3. The dissociation of H^2H^3 is considered. The percentage of dissociation of H^3 and H^2 and other hydrogens at a total pressure of one atmosphere calculated from the equilibrium constant. Tabulations of data are included. Equilibria of the isotopic hydrogens among themselves are calculated.

165 Jones, W. M. "Thermodynamic Functions for Tritium and Tritium Hydride. The Equilibrium of Tritium and Hydrogen with Tritium Hydride. The Dissociation of Tritium and Tritium Hydride." J. Chem. Phys. 16, 1077-81(1948). (AECD-1863; LADC-493; LA-656).

The heat capacity, entropy, internal energy and free energy are calculated to 2500°K for H^3 and HH^3. The distribution of H^3 between the ortho and para states is considered. The equilibrium constant for the formation of HH^3 from H and H^3 is calculated from 50 to 2500°K. The dissociation of H^3 and HH^3 into the atoms is discussed. The dissociation equilibria of H, H^2, and HH^2 have been recalculated. The bearing of the radioactivity of H^3 and HH^3 on the attainment of thermodynamic equilibrium is briefly considered.

166 Joris, G. G. and Taylor, H. S. "The Use of Tritium in the Determination of the Solubility of Water in Solvents." J. Chem. Phys. 16, 45-51(1948).

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A new method for the detn. of the soly. of water in hydrocarbons is based on the use of H^3 as tracer for the dissolved water. The method is applicable to the detn. of the soly. of water in compds. in which it is sparingly sol. The soly. of water in C_6H_6 is, in g. per 100 g. C_6H_6, 0.030 at 10°, 0.0425-0.0445 at 20°, 0.054 at 26°. These data are compared with those of 5 other investigators.

167 King, L. D. P., Robinson, E. S., Goldstein, L. and Bentzen, F. L. The Variation with Neutron Energy of the n(He^3,p)H^3 Reaction Cross Section. Sept. 8, 1948. (AECD-2281; LADC-558).

This document is an abstract; it is reproduced below in its entirety.

The total neutron absorption cross section of He^3 was compared with that of B^{10} enriched BF_3 gas in the approximate energy range of 0.025 - 0.001 electron volts. The constancy of the product σ times v, v denoting the neutron velocity, has been established for He^3 in this energy range. This "1/v" variation of the total cross section refers to the n(He^3,p)H^3 reaction as established by Coon and Hughes. This law points toward the apparent existence of a broad excited level in the He^4 nucleus whose energy is some 20 Mev. above its ground state.

168 Kundu, D. N. and Pool, M. L. "The (H^3,p) Reaction in Rhodium and Colbalt and Probable Evidence of the Di-neutron." Phys. Rev. (2) 73, 22-6(1948).

By H^3 bombardment, two neutrons have been introduced into Rh and Co nuclei according to reactions $Rh^{103}(H^3,p)Rh^{105}$ and $Co^{59}(H^3,p)$-Co^{61}, with half-lives of 35 hrs. and 1.75 hrs., resp. The mechanism appears to be an Oppenheimer-Phillips process with H^3. The results are interpreted in the light of the di-neutron (${}_0n^2$). It is believed that ${}_0n^2$ may exist under the phys. conditions of the expts. reported.

169 Markow, M. A. "On the Theory of β-Disintegration in the Case of a Low Upper Limit of the β-Spectrum and on the Mass of Neutrino." Zhur. Eksp. i Teoret. Fiz. 18, 903-6(1948).

The β-disintegration is examined on the assumption of a non-zero mass of a neutrino. It is found that in those cases in which the upper limit of the β-spectrum is low the neutrino mass plays a different part in different theories of the β-disintegration. The properties of H^3 serve as an illustration of these results. (See Konopinski, Phys. Rev. 72, 518 (1947).)

170 Melander, L. "On the Determination of Radioactive Hydrogen." Acta Chem. Scand. 2, 440-6(1948).

The author has devised a method whereby H^3 determinations may be made accurately within ±2% without the use of a high-vacuum pump or cooling agents such as liquid air. The H^3 sample, assumed present as water, is reduced to H with Mg turning and a part of the active H gas introduced together with methane into a Geiger-Müller tube. It is shown that the measured activity is proportional to the amount of H^3 present in the counter tube, holding independently of the total H pressure and the absolute amount of H^3 over large intervals. A schematic drawing and a picture of the apparatus as well as graphs of the measured activity are shown.

1948

171 Nelson, E. B. and Nafe, J. E. The Hyperfine Structure of Tritium. Sept. 15, 1948. (AECD-2350; CUD-11; DR-1072).

This document is an abstract; it is reproduced below in its entirety.

The h.f.s. of the ground state of tritium was measured by the atomic beam magnetic-resonance method. The apparatus previously used in the measurement of the h.f.s. of H and H^2 was modified to permit the recirculation of a small sample of H^3. The frequency of the field independent, central Zeeman component of the transition $F = 1 \rightleftarrows F = 0$ gives the h.f.s. almost exactly with field correction of less than 0.001 Mc. The mean of three independent determinations of the h.f.s. in different weak magnetic fields is 1516.702 + 0.010 Mc. The probable error is caused by the uncertainty in the Doppler correction and possible asymmetry in the resonance line causing a shift of the center of the line. The reproducibility of determining the center of the resonance line was ±0.002 Mc. The theoretical value of the h.f.s. based on the triton-proton moment ratio (F. Black, A. E. Graves, M. Packard, and R. W. Spence, Phys. Rev. 71, p. 551, (1947)) and the value of the h.f.s. (J. E. Nafe and E. B. Nelson, Phys. Rev. 73, p. 718(1948)) of H is 1516.709 ± 0.915 Mc. The theoretical and experimental values agree within the probable error in the ratio of the moments, 1 part in 10^5. This close agreement is in accord with the calculations of Teller (Pocono Conference, sponsored by the National Academy of Science, April 1, 1948), who has considered the detailed interaction of the electron with the elementary particles of the triton.

172 Pruett, J. R. "Tritium and the Mass of the Neutrino." Phys. Rev. (2), 73, 1219(1948).

Tritium appears to have an enormously short $T_{1/2}$ (10.20 years) for its energy release (11-15 kev.). Konopinski has shown this could be explained on the basis that an unobserved part of the energy is released in the form of a (anti) neutrino of very small but quite real mass.

173 Rarita, W. "Deuteron and Triton Methods." Phys. Rev. (2), 74, 1799-1801(1948).

Some methods of accurately calculating the depths of differently shaped potentials of the deuteron for non-central forces are reported. For a square well, the radial S and D wave functions u and w outside the well are known. Inside the range of interaction a general expansion in terms of modes is assumed and the modes for u and w are taken as Bessel functions of order one-half and five-halves, respectively. The wave-lengths of these modes are determined by requiring the continuity of the logarithmic derivative. Using the variational principle for one mode and then two such modes, values of 95% and 99% of the full binding energy are obtained. With an exponential multiplied by a power series in the interparticle distance as the modes, the joining condition was modified so as to require continuity only at the potential edge. Since the results thus obtained for the square well were excellent, the method was extended to the exponential and meson potentials. The accurate depths for these potentials were calculated with these modes as initial trial wave function for the iteration-variational method developed by Feshbach and Schwinger (unpublished communication). The relaxed continuity procedure was successfully applied both without and with tensor forces to the triton problem.

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174 Roberts, J. H. A Proposed Method of Measuring Neutron Energies by the (n,α) Reaction in Li^6 Using Nuclear Emulsions. Los Alamos Scientific Laboratory. Sept. 3, 1948. (LAMS-779; LADC-586).

Method of measurement using Li or Li^6 loaded photographic plates discussed. Vector diagram and graph of angle between α and $(H^3)^+$ track vs. n energy given for $Li^6(n,\alpha)H^3$ reaction.

175 Sachs, R. G. "Phenomenological Theory of Exchange Currents in Nuclei." Phys. Rev. (2), 74, 433-41(1948).

On the assumption that the interaction between nuclear particles involves a space exchange operator, it is shown that an addition must be made to the conventional current density for the nucleons in order to establish the equation of continuity within the nucleus. A general expression is found for this exchange magnetic moment. This phenomenological theory has application to the calculation of magnetic moments of nuclei and to the calculation of transition probabilities for the absorption and emission of radiation by nuclei. In this paper, application is limited to the exchange moments of H^3 and He^3. It is found that the exchange moments are six or seven times too small to account for the observed moments. In view of results obtained by Villars, it is concluded that the important contributions to the magnetic moment are directly related to the properties of the field (meson field) which describes the nuclear interaction, so the exchange moment may be of use for obtaining direct information concerning the nature of this field.

176 Smith, J. W. "Recent Advances in Science. General and Physical Chemistry." Science Progress 36, 101-12(1948).

Reviews the history of the discovery and determination of properties of H^3, and its use as a tracer in chemical investigation.

177 Taschek, R. Preliminary Results on the Cross-Section of the Reaction $T^3(d,n)He^4$ Between 1.0 Mev. and 2.5 Mev. Deuteron Energy. Feb. 2, 1948. (AECD-2250; LADC-510).

The reaction $H^3(d,n)He^4$ has been studied for deuterons of energies 1.0 Mev. to 2.5 Mev. (triton energies $\frac{3}{2}$ E_d) both to determine the differential and total reaction cross sections and to study the use of this reaction as a sourve of high energy neutrons. The availability of small but sufficient quantities of H^3 made the acceleration of deuterons of energies above 1 Mev. on to gaseous H^3 seem the logical method of producing the reaction and observing the reaction products, α particles and neutrons. A special target allowing angular distribution measurements of α particles to be made in a small gas volume is described and the essentials are indicated. A schematic diagram of the H^3 storage and handling system is shown; heated U shavings provided a completely satisfactory method of evolving the H^3 stored as UH_3 in the cold U when not in use. Since the total amount of gas available at one time was only about 10 to 15 cm^3 at NTP, the mercury lift through the 500 cm^3 bulb was used to make a complete transfer of gas at maximum efficiency from uranium pump to target and vice versa possible. Auxiliary connections could be made to supplies of H and H^2 gas as shown in the diagram. The following total reaction cross sections are reported: 0.15 ± 0.02 barns at 1.0 Mev., 1.5 Mev. and 2.0 Mev.; 0.135 ± 0.03 barns at 2.5 Mev. This last cross section is believed to be inaccurate because of unsatisfactory measurements.

178 Taschek, R. F. and Barschall, H. H. Angular Distribution of 14-Mev. Neutrons Scattered by Protons. Sept. 8, 1948. (AECD-2292; LADC-557).

This document is an abstract; it is reproduced below in its entirety.

Monoenergetic 14 Mev. neutrons were produced by bombarding a tritium target with 200-kev. deuterons. Proton recoils originating in a thin polythene radiator could pass through three proportional counters arranged in a direction perpendicular to the radiator, and coincidences in the three counters were observed. By rotating the foil and counters about the center of the foil, the angular distribution of the recoiling protons could be measured. The angular resolution was ±12° in the center of mass system. Protons corresponding to neutrons scattered through 90°, 120°, 150° and 180° in the CM system were observed. Within the statistical accuracy of five per cent at each angle, the angular distribution of the scattered neutrons appeared isotropic in the center of mass system.

179 Taschek, R. F. and Gittings, H. T. "Observations of Naphthalene Scintillations Caused by Tritium β-Rays. Phys. Rev. (2), 74, 1553-4(1948). (AECD-2273; LADC-552).

Scintillations produced in com. naphthalene by β-rays from H^3 and by Bremsstrahlung from H^3 occluded in Ta were studied. The lower limit for the conversion efficiency from β-ray to visible light energy is 6%. The rise-time and total pulse-length are 0.05 and 0.2 microsec., resp.

180 Thellung, A. and Villars, F. "The Magnetic Moment of H^3 and He^3 in the Møller-Rosenfeld Theory of Nuclear Forces." Phys. Rev. (2), 73, 924-5(1948).

A systematic investigation was made to see whether the Møller-Rosenfeld model of nuclear forces can account for the magnetic moment M of the H^3 nucleus. M is composed of 3 parts: (1) the sum of the proper moments of all nucleons, (2) the orbital moment, and (3) the exchange moment, which is the sum of the contributions from the vector and the pseudoscalar field. The calcn. shows that $M(He^3)Av. = \mu n - 0.013$ n.m., and $M(H^3)Av. = pr + 0.013$ n.m. The value for H^3 is incompatible with the exptl. value of $\mu pr + 0.186$ n.m.

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181 Allan, D. L. and Poole, M. J. The Ninety-Degree Excitation Function of the Reaction $T(d,n)He^4_2$. Dec. 1949. Atomic Energy Research Establishment. (AERE-N/R-449).

The symmetrical cross section of the reaction, D(t,n)α, has been investigated over an energy range of 100-200 kev. for the bombarding tritons. Two methods have been used. First the yield of α particles from a thick heavy ice target was measured per unit charge of incident beam and the variation of cross section deduced from the gradient of this excitation curve and the range-energy relation for tritons in heavy water. The cross section was compared with that for

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the deuterium-deuteron reaction measured in the same way. In the second method a direct comparison was made between the yield of α-particles from the deuterium-triton reaction and the yield of protons from the deuterium-deuteron reaction when a beam containing both deuterons and tritons was passed through a heavy water vapor target. (The energy loss in this target was calculated as only a few hundred electron volts). To do this a simultaneous observation was made of the protons and α-particles using the same counter. In both cases the results were similar; the curve giving the ratio between the symmetrical cross sections for the D-t and D-d reactions (at equal relative velocities of the particles concerned) showed a peak in the region of 150-kev. energy. Much greater reliance can be placed on the results of the thin target experiment, as a more accurate measurement of the voltage of the set was possible at the time of these experiments, and the voltage does not enter critically into the calculation of the cross section, as is the case in the thick target experiment. A brief account is given of the high voltage equipment.

182 Allan, D. L. and Poole, M. J. "Resonance Effects in the Reaction H_1^3(d,n)-He_2^4." Nature 164, 102-3 (1949).

The excitation function of the reaction $H^3_+ \ H^2 = He^4_+ \ n_+$ 17.6 Mev. has been studied over an energy-range of 90-190 kev. using a low-voltage accelerator. A thick target of heavy ice was bombarded with a beam containing H^3 ions, and the α-particles emitted were observed in a proportional counter. Evidence has been found for a resonance in the cross section of the reaction for an energy of the incident H^3 ions of (155 ± 15) kev. The cross section at the peak of the resonance is several barns.

183 Argo, H. V., Gittings, H. T. Hemmendinger, A., Jarvis, G. A., Mayer, H. and Taschek, R. F. Observation of 20 Mev. Gamma Rays from the $T^3(p,\gamma)He^4$ Reaction. n.d. (AECU-155; LADC-645).

This document is in abstract form; it is reproduced below in its entirety.

A comparison of the absorption in Al of β-rays produced by thick-target γ-rays from the $H^3(p,\gamma)He^4$ and $Li^7(p,\gamma)Be^8$ reaction has been made using triple coincidence counters. A thick target of H^3 absorbed in a disc of Zr and an incident proton energy of 1.01 Mev. was used. An estimate of total cross section for this reaction will be given.

184 Argo, H. V., Gittings, H. T., Hemmendinger, A., Jarvis, G. A. and Taschek, R. F. Properties of the $T^3(p,\gamma)He^4$ Reaction. Los Alamos Scientific Laboratory. n.d. (AECU-723; LADC-759).

Yield and angular distribution measurements on the $H^3(p,\gamma)He^4$ reaction have been made for protons up to 2.5 Mev. The yield indicates a resonance in the He^4 nucleus at a proton energy of about 2.5 Mev., giving an excited level at 21.6 Mev. The angular yield of the γ rays fits an $A + B \sin^2\theta$ distribution very well, suggesting that the γ rays are due predominantly to a transition from the $^1p_1$ state to the $^1S_0$ state. An aluminum absorption curve for the secondaries produced in a lead radiator was taken, and a direct comparison made with the 17.5 Mev. γ rays from the $Li^7(p,\gamma)Be^8$ reaction, showing that the $H^3(p,\gamma)He^4$ γ rays are of higher energy.

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185 Avery, R. and Adams, E. N., II. "Exchange Moments of Hydrogen^3 and Helium^3." Phys. Rev. (2), 75, 1106-7(1949).

Methods for calcg. exchange moments are discussed; the calcd. exchange moment of H^3 is 0.016 n.m. Calcns. for He^3 show that the small difference between the H^3 and He^3 wave functions have negligible effect on the sums of the ordinary and exchange moments. 10 references.

186 Bernstein, W. and Ballentine, R. Gas Phase Counting of Low Energy Beta Emitters. Brookhaven National Laboratory. n.d. (AECU-680).

A proportional counter has been designed to detect soft β-emitters in the gas phase. Data is presented to illustrate the applicability of the counters to the detection of C^{14}, S^{35} and H^3. Various partial pressures of $C^{14}O_2$ have been investigated to determine the effects on the counter properties. Corrections have been made for the counter ends, and the memory effects are described. An energy spectrum is presented for H^3 to determine the low energy limit of the instrument.

187 Bigeleisen, J. Dissociation and Exchange Equilibria of the Tritium Halides. Brookhaven National Laboratory. n.d. (AECU-674).

The ratios of the partition functions of the tritium halides to their respective hydrogen halides have been calculated. These are combined with one another to give the exchange equilibria between the six pairs of tritium and hydrogen halides. The exchange equilibria with water are calculated. From the exchange equilibria between the tritium halides and hydrogen and the free energy of dissociation of the hydrogen halides, the dissociation equilibria of the tritium halides have been calculated. The experimental data on the dissociation of HI are reviewed, and it is shown that the data of Taylor and Crist (J. Am. Chem. Soc. 65, 1377(1941)) on DI and HI are self-consistent as well as in good agreement with theory. The heat of formation of HI at absolute zero is found to be −1007 + 10 calories per mole.

188 Bigeleisen, J. "The Validity of the Use of Tracers to Follow Chemical Reactions." Science 110, 14-16, 149(1949).

Estimates of the max. ratios of the sp. rate consts., at 25°, for reactions involving many of the common tracers were calcd. and tabulated. The max. isotope effects in the rates of reaction decrease as the at. no. increases. The isotope effect decreases with the amt. of reaction. H^2, H^3, C^{13}, and C^{14} may require special consideration in nonequil. systems.

189 Blau, M. "Grain Density in Photographic Tracks of Heavy Particles." Phys. Rev. (2), 75, 279-82 (1949).

The relation between grain density in photographic tracks and particle energy has been derived theoretically assuming that the probability that a grain be developed is given by $P = c(1 \cdot \exp[-b(dE/dR)^{1/2}])$. Using a single pair of parameters b and c all experimental curves so far published for α-particles, tritons, protons, π and μ mesons (Univ. of Bristol) can be represented with this equation. The agreement between experiments and theory is very satisfactory.

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190 Boggild, J. K. and Minnhagen, L. "A Cloud-Chamber Study of the Disintegration of Lithium by Slow Neutrons." Phys. Rev. (2), 75, 782-5(1949).

The ranges of tritons and α-particles formed in the slow neutron reaction $Li^6(n,\alpha)H^3$ have been measured in a cloud chamber and found to be $R_\alpha = 10.4 \pm 0.2$ mm. and $R_3H = 60.0 \pm 0.6$ mm. in air at N.T.P.; the corresponding Q values, derived from the blue-printed Cornell energy vs. range curves, disagree, and the Q derived by the proton relation is also in disagreement with other data. The discrepancies suggest the establishment of a new point on the proton energy vs. range curve, viz., $R_p = 20.0$ mm., $E_p = 0.88$ Mev., which means a reduction of the energy by about 6%.

191 Bowers, W. A. and Rosen, N. "H^3 and the Mass of the Neutrino." Phys. Rev. (2), 75, 523(1949).

Recent work on the half-life of H^3 (Novick, Phys. Rev. 72, 972(1947)) and its β-spectrum (Curran et al, Nature 162, 302(1948)) seems to remove the discrepancy noted by Konopinski (Phys. Rev. 72, 518(1947)), when considering the earlier data on H^3 (Watts and Williams, Phys. Rev. 70, 640(1946)); O'Neal and Goldhaber, Phys. Rev. 58, 574 (1940)) if a zero rest mass is assumed for the neutrino. Using the more recent data, the values of $|M|^2$ft. obtained for both H^3 and He^6 were found to be of the same order of magnitude as the value for H^6 given by Konopinski. This result is in agreement with the conclusions of several workers (Curran et al, Nature 162, 302(1948); Cook et al, Phys. Rev. 73, 1395(1948)) concerning the neutrino mass based on the shapes of β-energy distribution curves near their upper limits.

192 Bretscher, E. and French, A. P. "Low-Energy Cross Section of the Deuterium-Tritium Reaction and Angular Distribution of the α-Particles Emitted." Phys. Rev. (2), 75, 1154-60(1949). (AECD-2211; LADC-537).

The thick-target yield of the reaction $H^3 + H^2 \rightarrow \alpha + n + 17.6$ Mev. was measured, with a heavy-ice target, and observations were made on the angular distribution of the α-particles. Expts. were conducted in the region 15-125 kev. incident triton energy; in this range the angular distribution is isotropic in the center-of-gravity system. The cross section for the reaction as a function of energy was evaluated from the thick-target yield measurements. It rises more rapidly with energy than is required by a simple Gamow function.

193 Brueckner, K. and Powell, W. M. "Charged Particles Emitted by Carbon Bombarded by 90 Mev. Neutrons." Phys. Rev. (2), 75, 1274-5(1949).

Secondary charged particles emitted from carbon nuclei bombarded with 90-Mev. neutrons have been measured in a series of cloud chamber experiments. Protons with energies from 32 to 107 Mev., deuterons from 25 to 124 Mev., and tritons from 56 to 95 Mev. could be identified with very small uncertainty in the type of particle and about a ±6% probable error in energy. The angular range from 0° to 36° was included, with a probable error of about ±2° in angle. The cross section for the production of the particles observed is 24 ± 12 millibarns.

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194 Brues, A. M. and Lisco, H., ed. Biological and Medical Divisions Quarterly Report May, June, July, 1949. (ANL-4333).

Pages 136-8 contain a summary and tabulated results on the toxicity of tritium oxide to mice.

195 Byatt, W. J., Rogers, F. T., Jr. and Waltner, A. "On the Beta-Particle Spectrum from the Decay of Tritium." Phys. Rev. (2), 75, 909(1949).

A reduction of previously reported data on the β-particle spectrum from the decay of H^3 (Phys. Rev. 74, 699(1948)) has been completed and the results obtained are discussed. By numerical solution of the rather complicated relevant integral equation, a differential distribution of true track lengths was obtained; this, after consideration of the small effects of straggling, was converted to a differential energy-distribution; finally, this last distribution was compared in the standard way with the theory of Fermi. The cloud-chamber data result in an extrapolated end-point energy of 17.0 kev., which is in extremely good agreement with the 16.9 kev. recently obtained (Nature 162, 302(1948)) by Curran, Angus, and Cockroft.

196 Clapp, R. E. "The Binding Energy of the Triton." Phys. Rev. (2) 76, 873-4(1949).

A variational calcn. of the binding energy of the H^3 nucleus was made by using the Rarita-Schwinger interaction (square well with tensor force), modified to include a charge exchange factor $-(\tau_i - \tau_j)/3$. D-states not included in the calcns. of Gerjuoy and Schwinger or Feshbach and Rarita make a substantial contribution to the binding energy.

197 Coon, J. H. Disintegration of He^3 by Fast Neutrons. Los Alamos Scientific Laboratory. Dec. 14, 1949. (AECD-2856; LAMS-984).

The cross section for the $He^3(n,p)H^3$ reaction has been measured using fast neutrons over the energy range from 0.4 to 3.0 Mev. The apparatus and technique have been previously described (Coon and Nobles, Phys. Rev. 75, 1358 (1949)). The observed values of the cross section drop off continuously from 0.8 to 0.5 barn over this neutron energy range. The estimated probable error is 25%. Deviations from the "1/v" law by about 50% suggest an energy level in the He^4 nucleus in the region of 22 Mev.

198 Curran, S. C., Angus, J. and Cockroft, A. L. "The β-Spectrum of Tritium." Phys. Rev. (2), 76, 853-4 (1949).

The shape of the spectrum near the end point was examd. Curves are calcd. for true upper energy limits (E_0) of 18.0 and 18.6 kev., with a neutrino mass $\mu = 0$ kev., and for $E_0 = 18.0$ kev. and $\mu = 1$ kev. For $\mu = 0$ kev., exptl. results lie between $E_0 = 18.0$ and $E_0 = 18.6$ kev.; for $E_0 = 18.0$ kev., expt. shows that $0 < \mu < 1$ kev.

199 Curran, S. C., Angus, J. and Cockroft, A. L. "Investigations of Soft Radiations. II. The β-Spectrum of Tritium." Phil. Mag. (7), 40, 53-60(1949).

The β-spectrum of tritium is investigated between 0.5 and 17.9 kev. The spectrum is found to be simple and in

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reasonable agreement with the theory of Fermi. A neutrino mass 0.002 of the electron mass is derived. The exptl. values appear to be inconsistent with a zero mass for the neutrino. The mass appears to be certainly less than 1/300 of the electron mass.

200 Dieke, G. H. Progress Report for the Period October 15, 1948-March 31, 1949. The Spectra of the Hydrogen Molecules Containing Tritium. Johns Hopkins University. 12p. (JHUD-1).

Outline of project to investigate the molecular spectra of H^1H^3, H^2H^3, and H^3_2. The general plan of the project and a brief review of previous work is given.

201 Dieke, G. H. Progress Report for the Period April 1, 1949-June 30, 1949. Johns Hopkins University. July 4, 1949. (JHU-2).

Progress on photography and analysis of results of spectra of H^3H^1 and H^3_2 is reported. No numerical data given.

202 Dieke, G. H. and Tomkins, F. S. "The Molecular Spectrum of Hydrogen. The Fulcher Bands of Th and T_2." Phys. Rev. (2), 76, 283-9(1949). (AECU-236).

The spectra of H^3H^1 and H^3_2 were photographed under high dispersion. An analysis of the $3p^3\Pi - 2S^3\Sigma$ bands of these mols. is presented, and the consts. of the two states are given.

203 Erickson, K. W. Differential Cross Section as a Function of Angle for the D(d,p)T Reaction for 10.9-Mev. Bombarding Deuterons. Los Alamos Scientific Laboratory. Nov. 16, 1949. (AECU-724; LA-980).

The general outline of the experiment reported here is as follows: a thin H^2 gas target was bombarded with 11-Mev. deuterons from the 42-in. Los Alamos cyclotron; reaction protons emitted from this target chamber by virtue of the $H^2(d,p)H^3$ reaction were counted by means of a proportional counter placed at various angles to the beam; the main beam continued through the target into a Faraday cage by means of which the total number of deuterium particles bombarding the target was obtained. These data, together with the geometry of the secondary particle system, permitted the calculation of the desired differential cross section. The total cross section for the reaction has been calculated to be 0.063 barns. The apparatus and procedure for this experiment are discussed in detail. The following appendixes are included: A. derivation of equation for calculating cross section; B. transformation relations between lab and center of mass systems; C. relative stopping power of nylon; D. results, intermediate and final. 18 references.

204 Feshbach, H. and Rarita, W. "Tensor Forces and the Triton Binding Energy." Phys. Rev. (2), 75, 1384-8(1949).

The binding energy of the triton has been calculated variationally employing the Hylleraas expansion for the trial wave functions, thus permitting a systematic improvement in the binding energy. The procedure used was tested by applying it to the binding energy problem of the deuteron with tensor forces. The present theory, assuming a rectangular-well shape with a range of 2.8×10^{-13} cm. for all the internucleon potentials, yields a H^3 binding energy 40%-50% of the experimental value. Various suggestions for resolving this dilemma are discussed.

205 Franzen, W., Halpern, J. and Stephens, W. E. "Ionization Chamber Study of the Disintegration of He^3 and N^{14} by Thermal Neutrons." Phys. Rev. (2), 77, 641(1949).

The total ionization produced by the reactions $He^3(n,p)$ and $N^{14}(n,p)$ in a gas mixture consisting mainly of argon was measured by means of a cylindrical ionization chamber operated under conditions of electron collection. High resolution was achieved by suitable choice of chamber geometry and by use of a low noise level amplifier. The total ionization charges collected from Po α-particles, from the disintegration products of $He^3(n,p)$ and from those of $N^{14}(n,p)$ are found to be in the ratio 1:0.145 ± 0.002:0.119 ± 0.001, respectively. Comparison with Po α-particles on the assumption of a constant average energy per ion pair in argon then yields reaction energies of 766 ± 10 kev. for $He^3(n,p)$ and 630 ± 6 kev. for $N^{14}(n,p)$. The difference between these energies agrees well with the difference between the end points of the β-ray spectra of C^{14} and H^3. This agreement supports the assumption of a proportionality between energy and ionization in argon independent of particle type. A value of 785 ± 6 kev. is computed for the neutron-hydrogen mass difference from these data.

206 Franzen, W., Halpern, J. and Stephens, W. E. "Ionization Measurement of $He^3(np)$ and $N^{14}(np)$ and the Neutron-Hydrogen Mass Difference." Phys. Rev. (2), 76, 317-8(1949).

The pulse-size distribution arising from electron collection of the ionization produced by the reactions $He^3(n,p)H^3$ and $N^{14}(n,p)C^{14}$ induced by slow neutrons was observed using a cylindrical ionization chamber filled with an A-N-He (enriched in He^3) mixture. Pulse-height distribution curves are shown. If a linear relation between energy and ionization is assumed in A, in accordance with the results of Jesse, Phys. Rev. 74, 1259A(1948) and 75, 1110(1949), then the energy equivalents of the total ionization produced in $He^3(n,p)$ and $N^{14}(n,p)$ are 764 ± 10 kev and 628 ± 4 kev., respectively, when a direct comparison is made with Po α-particles (assumed to have an energy of 5298.4 kev.). The results obtained support the assumption of a constant average energy per ion pair in A. The energies obtained agree well with the thresholds for the inverse (p,n) reactions, 620 ± 9 kev.[8] and 764 ± kev.[9], respectively, and an ionization determination of $N^{14}(n,p)$, using total ion collection of 630 ± 10 kev.[10]. Assuming zero neutrino mass, the results lead to a neutron-H mass-difference of 783 ± 4 kev.

207 Graves, E. R. and Meyer, D. I. "End Point of the Tritium Beta-Ray Spectrum." Phys. Rev. (2), 76, 183(1949).

A new method has been used to measure the end point of the tritium β-ray spectrum. The Bremsstrahlung produced by H^3 β-rays stopped by the atoms of heavy element, namely Zr or Ta, was counted with a thin end window Geiger counter. Aluminum absorbers were inserted between the source and the counter to measure a counting rate versus absorber

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thickness curve. The analysis of the data is accomplished by trial and error fitting of the absorption curve. Assuming zero mass for the neutrino and a trial end point, a Fermi β-spectrum is calculated. Using this, an x-ray spectrum is calculated, utilizing $I_v d_v = CZ(v_0 - v)d$ to give the continuous x-ray spectrum produced by a β ray of energy hv_0. The complete x-ray spectrum produced by the β spectrum is derived by summation of the contributions of each interval of the β-spectrum. The attenuation of this x-ray spectrum by Al is calculated. Small corrections for the variation of counter sensitivity with energy are applied. The end point of the β-ray spectrum is deduced to be 18.0 kev. The error is estimated at −0.5 kev.

208 Graves, E. R., Rodrigues, A. A., Goldblatt, M. and Meyer, D. I. "Preparation and Use of Tritium and Deuterium Targets." Rev. Sci. Instruments 20, 579-82(1949). (AECU-207).

H^3 and H^2 were impregnated into Ta and Zr targets by heating the foils in a vacuum to degas them and then admitting the isotope to the system. Degassing was accomplished by a final temp. of 2200° for Ta and 1800° for Zr. The app. used is described. The method of use of these targets is also described.

209 Hammel, E. F. Some Calculated Properties of Tritium. Los Alamos Scientific Laboratory. n.d. (AECU-647; LADC-727).

The application of quantum theory to condensed permanent gases by DeBoer resulted in a modified law of corresponding states that has been successfully used to predict a number of properties of He^3 which were later confirmed by experimental data. In this paper DeBoer's modified law is applied to H^3, and vapor pressures within the temperature range 12.2 - 33.9°K, critical constants, triple-point constants, and several molecular constants have been calculated. It is believed that an even closer agreement between theoretical and experimental values will be observed when experimental data on H^3 become available than was found for He^3.

210 Hanna, G. C., Kirkwood, D. H. W. and Pontecorvo, B. "High Multiplication Proportional Counters for Energy Measurements." Phys. Rev. (2), 75, 985-6(1949).

The essentials of the technique of investigating L-capture (Phys. Rev. 75, 982,(1949)) in the A^{37} and H^3 spectra (Phys. Rev. 75, 983(1949)) by means of proportional counters are described and the problems of linearity and "line-width" are discussed. The results obtained have been tabulated and plotted; they are found to be most consistent with a mean square deviation of "n", the estimated mean number of ion pairs released by radiation. Since less spread is introduced by the gas amplification than would be expected from the theory, an attempt is now being made to formulate a more accurate theory of the process.

211 Hanna, G. C. and Pontecorvo, B. "The β-Spectrum of H^3." Phys. Rev. 75, (2), 983-4(1949).

The proportional counter technique previously described (Phys. Rev. 74, 497(1948); 75, 985(1949)) has been used to study the β-spectrum of H^3, an investigation of which has recently been reported by Curran et al., (Nature 162, 302 (1948)). Two counter types were used with fillings of Xe, A, CH_4, H, H^3, and A^{37}. The H^3 spectrum in the region of the end-point is shown as well as a Kurie plot of the H^3 spectrum; the latter is compared with the theoretical curve. The results indicate that the initial assumption of a zero neutrino mass is correct within the limits of the experimental error. From the data obtained the extrapolated end-point has been determined as 18.9 ± 0.5 kev. which is somewhat higher than previous values.

212 Hanson, A. O. and Taschek, R. F. Monoenergetic Neutrons from Charged Particle Reactions. National Research Council. n.d. (NP-852).

The primary emphasis in the discussion is on those reactions which have been most widely used as sources of monoenergetic neutrons. The reactions, which are discussed in detail, are those involving light nuclei, namely $H^2(d,n)He^3$, $Li^7(p,n)Be^7$, and $C^{12}(d,n)N^{13}$. With H^3 having recently become available for use as either a projectile or as target material, the reactions $H^3(p,n)He^3$ and $H^3(d,n)He^4$ have already proved useful as sources of monoenergetic neutrons. Neutron energies obtainable from these reactions are shown as a function of the energy of the incident particle. The reactions $V^{51}(p,n)Cr^{51}$, $Sc^{45}(p,n)Ti^{45}$, and other (p,n) and (d,n) reactions are also discussed. 49 references.

213 Hemmendinger, A., Jarvis, G. A. and Taschek, R. F. "Scattering of Protons by Tritons." Phys. Rev. (2), 76, 1137-41(1949).

The proton-triton differential scattering cross section has been measured for laboratory angles between 45° and 135° and proton energies between 0.7 and 2.5 Mev. In this angular range the scattering is predominantly nuclear and shows a rapid increase in intensity for angles greater than 90° in the center of mass system. Some indications of anomalous behavior near the threshold for $H^3(p,n)He^3$ are reported.

214 Jarvis, G. A., Hemmendinger, A., Argo, H. V. and Taschek, R. F. Differential Cross Sections for the Reaction $T^3(p,n)He^3$ from 1 to 2.5 Mev. Proton Energies. Los Alamos Scientific Laboratory. 1949. (AECU-157; LADC-647).

This document is in abstract form; it is reproduced below in its entirety.

The angular distributions of neutrons from the $H^3(p,n)He^3$ reaction have been measured in 200 kev. steps from the threshold at 1.019 Mev. proton energy up to 2.5 Mev. The distributions in the center of mass system were fitted with cosine series and integrated to obtain total cross sections. It is necessary to include cosine cubed terms to fit the data at higher energies. The total cross section rises to 0.55 barns at 2.4 Mev. proton energy and is still rising at a fairly rapid rate at this energy.

215 Jarvis, G. A., Hemmendinger, A., Argo, H. V. and Taschek, R. F. Reaction Constants for $T^3(p,n)He^3$. Los Alamos Scientific Laboratory. n.d. (AECU-717; LADC-747).

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Measurements of the differential and total cross sections for $H^3(p,n)He^3$ between the reaction threshold at 1.019 Mev. and 2.49 Mev. are reported. At the higher energies the neutron emission in the center of mass system is highly asymmetric and the energy dependence of the coefficients of a cosine expansion fit to the angular distribution is determined. Evidences for resonance effects are observed at the highest proton energies used, indicating an excited state in the continuum of the intermediate He^4 nucleus. The use of the reaction as a neutron source is discussed. 14 references.

216 Jenks, G. H., Ghormley, J. A. and Sweeton, F. H. "Measurement of the Half-Life and Average Energy of Tritium Decay." Phys. Rev. (2), 75, 701-2(1949).

Recently, Novick (Phys. Rev. 72, 972(1947)) and Goldblatt et al., (Phys. Rev. 72, 973(1947)) have found the half-life period of H^3 to be considerably less than the 30-year period previously accepted. The authors have determined the half-life of tritium as 12.46 ± 0.2 years, in agreement with the 12.1 ± 0.5 years reported by Novick. In addition the average energy of the H^3 decay was found to be 5.69 ± 0.06 kev. The calorimetric method used is described.

217 Jones, W. M. "Thermodynamic Functions for Tritium Deuteride. The Dissociation of Tritium Deuteride. Equilibria Among the Isotopic Hydrogen Molecules." J. Chem. Phys. 17, 1062-4(1949).

The heat capacity, entropy, internal energy, and free energy are calcd. to 2500°K. for H^2H^3 the dissocn. of H^2H^3 is considered, and equil. of the isotopic hydrogens among themselves are calcd.

218 Kahn, D. and Groetzinger, G. "Upper Limit for the (d,H^3) Reaction in Phosophorus." Phys. Rev. (2), 75, 906(1949).

P^{31} was bombarded with 7.5 Mev. deuterons in an arrangement which would detect the production of P^{30} if the cross section of the process is less than 5×10^{-30} sq. cm.; P^{30} was not found.

219 Keepin, G. R. and Roberts, J. H. "On the Measurement of the Energy of Fast Neutrons by Photographic Emulsions Loaded with Enriched Li^6." Phys. Rev. (2), 76, 154(1949).

Photographic emulsions of the NTA type, enriched in Li^6, were bombarded with neutrons from a mixed Po + Be source; in commercial lithium-loaded plates the disintegrations are masked by a high background of proton tracks. From 225 tracks produced by thermal neutrons from the thermal column of the Argonne heavy water pile, the ranges of the α-particle and of the triton were determined as $6.8 \pm 0.6\mu$ and $38.2 \pm 1.1\mu$, respectively. An analysis of the method indicates that it can be used to measure neutrons of energy less than 1 Mev. to a precision of at least 0.1 Mev. In addition to extending the photographic method to neutron energies below 1 Mev. this technique should also prove valuable in the measurement of the energy distribution of fast neutrons inside a material medium since collimation of the neutrons is not required and perturbations introduced by the detector are minimized.

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220 Knight, J. D., Novey, T. B., Cannon, C. V. and Turkevich, A. Some Activities from Tritium Bombardment in Neutron-Irradiated Li Salts: The (t,n) Reaction on Q and S. Decl. April 18, 1949. (AECD-2567).

The 112m F^{18} and 33m Cl^{34} have been produced and identified in neutron-irradiated Li salts containing O and S respectively. They are produced by bombardment of O^{16} and S^{32} by tritons coming from $Li^6(n,\alpha)H^3$. A preliminary search for P^{33} by (t,p) on P^{31} has been unsuccessful.

221 Melander, L. "Introduction of Substituents into the Aromatic Nucleus. Exploration of its Mechanism by Means of Isotopic H." Acta Chem. Scand. 3, 95-6(1949).

Nitration of H^3-contg. C_6H_6 and PhMe gives products having the same ratios of H^3 and H. This indicates a "π complex" rather than a pure S_E2 type of reaction. By the same H^3 method nitration of $C_{10}H_8$ in the 1-position follows the same mechanism. The chlorination of PhMe in the ortho position in the absence of catalyst and in the presence of light, in which Cl atoms probably remove H atoms, is found to prefer light atoms to heavy ones.

222 Natanson, L. "Nuclear Disintegration of Lithium by Fast Neutrons." Compt. rend. 229, 588-9(1949).

The reaction $Li^6(n,\alpha)H^3$ is studied in a photographic plate coated with a 100-μ sheet of Li irradiated with fast neutrons from a Ra source surrounded with Be. A value of 4.69 ± 0.10 Mev. is reported for the reaction energy.

223 Nelson, E. B. and Nafe, J. E. "The Hyperfine Structure of Tritium." Phys. Rev. (2), 75, 1194-8 (1949).

The hyperfine structure (h.f.s.) of the ground state of H^3 was measured by the at.-beam magnetic-resonance method. The frequency of the field-independent central Zeeman component of the transition ($F = 1 \leftrightarrow F = 0$) gives the h.f.s. almost exactly with a field correction of <0.001 Mc. The mean of 3 independent detns. of the h.f.s. in different weak magnetic fields is 1516.702 ± 0.010 Mc. The probable error is caused by the uncertainty in the Doppler correction and possible asymmetry in the resonance lines causing a shift in the center of the line. The reproducibility of detg. the center of the resonance line was ±0.002 Mc. The theoretical value of the h.f.s. based on the triton-proton moment ratio and the value of the h.f.s. of H is 1516.709 ± 0.015 Mc. The theoretical and exptl. values agree within the probable error of the moment ratio, 1 part in 100,000, which also proves that the spin of the triton is ½.

224 Pepper, T. P. "Relative Yields of the D-D Reactions at Low Energies." Can. J. Research 27, 143-50(1949).

By the simultaneous detection of the H^1, H^3, and He^3 particles in a thin window proportional counter the concurrent nuclear reactions $H^2(d,p)H^3$ and $H^2(d,n)He^3$ have been investigated throughout the deuteron energy range 26 to 63 kev. The ratio of the yield of the reaction $H^2(d,n)He^3$ was found to be 1.15 ± 0.15 throughout this energy range. There is some slight evidence for an increase in this ratio toward lower bombarding energies.

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225 Reid, J. C. and Tolbert, B. M. The Synthesis of Labeled Alpha Amino Acids. University of California Radiation Laboratory. Aug. 1, 1949. (AECU-437; UCRL-408).

The literature on the synthesis of isotopically labeled amino acids (both active and inactive isotopes) is reviewed, and a short comprehensive outline of the chemicals used is presented. The introduction of H^2, H^3, N^{15}, C^{13}, C^{14}, S^{34}, S^{35} and I^{131} into amino acids is discussed. 43 references.

226 Rosen, L., Tallmadge, F. K. and Williams, J. H. "Range Distribution of the Charged Particles from the D-D Reactions for 10-m.e.v. Deuterons: Differential Elastic Scattering Cross Section at 40 degrees, 60 degrees, and 80 degrees in the Center-of-Mass System." Phys. Rev. (2), 76, 1283-7(1949).

The differential H^2-H^2 elastic scattering cross sections were obtained: they have the ratio 1.00:0.51:0.42 resp. Only one group of protons was observed from the $H^2(d,p)H^3$ reaction. This indicates that the H^3 nucleus is not formed in an excited state in this energy region when He^4 is the compd. nucleus.

227 Ruddlesden, S. N. and Clarke, A. C. "Disintegration of Helium by π^- Mesons." Nature 164, 487-8(1949).

The energy spectra and relative probabilities of the three types of He^4-decay have been calculated on the following assumptions; the meson is captured from the lowest Bohr orbit; the whole mass (290 m_e) is converted into energy; the interaction energies are (a) ψ (r) or (b)$\sigma\cdot\nabla\psi(r)$, where $\psi(r)$ is the scalar meson wave function at the position of a proton and σ is the spin operator of the proton. Gaussian wave functions $\exp(-\alpha\Sigma r_{ij}^2)$, $1/\sqrt{\alpha} = 4.0 \times 10^{-13}$ cm.) are used for the nuclei and plane waves for the emitted particles. The transition probabilities are determined by the usual perturbation method. It was found that the relative probabilities for emission of a triton, deuteron or proton are 5:1:5 with interaction (a), or 12:1:25 with interaction (b). Only one energy (30 Mev.) is possible for the triton if the meson is completely absorbed; but, if a neutral meson is formed, a spectrum of energies will be observed. The probability of deuteron emission is rather small and is reduced further if the value of α in the deuteron wave function is reduced (corresponding to large radius). The normalized energy spectra of the protons are shown: (a) using interaction ϕ (r); (b) using interaction $\sigma\cdot\nabla\phi(r)$; (c) using a matrix element independent of the energies of the emitted particles. It is noted that variation of the parameter α in the nuclear wave functions does not greatly affect the results.

228 Sherk, P. M. "Bound-Electron Creation in the Decay of Tritium." Phys. Rev. (2), 75, 789-91 (1949).

The relative probabilities of K creation and β-emission are calcd. for both mol. and at. H^3. This ratio is 0.0035 for the mol. and 0.0065 for the atom, if it is assumed that the max. kinetic energy of the β-rays is 16.9 kev.

229 Slack, L., Owen, G. E. and Primakoff, H. "The Maximum β-Energy Release in Tritium." Phys. Rev. (2), 75, 1448(1949).

The max. value of the energy release of H^3 is 18.6 ± 0.2 kev.; of He^6, 3.5 ± 0.6 Mev. Values of $|M|^2$ft. are, resp., 3360 ± 200 and 6300 ± 3000. Complete consistency is established between recent H^3 and He^6 measurements and the application of the Gamow-Teller selection rules to these β-active nuclei.

230 Tallmadge, F. K., Williams, J. H., and Rosen, L. Range Distribution of the Charge Particles from the D-D Reactions for 10-Mev. Deuterons: Differential Elastic Scattering Cross Section at 20 Deg., 30 Deg., and 40 Deg. in the Laboratory System." n.d. (AECU-91; AD-14).

This document is an abstract; it is reproduced below in its entirety.

Photographic plates were used to determine the range distributions of all charged particles from the H^2-H^2 reactions as well as the absolute intensity of the elastically scattered deuterons for 10-Mev. deuterons from the Los Alamos cyclotron. These measurements were made at 40 deg., 30 deg., and 20 deg. (laboratory coordinate system) with respect to the incident beam which was focused on a "thin" deuterium gas target 15 ft., from the cyclotron. At 40 deg. all of the charged particles from the above reactions (protons, tritons, He^3's and elastically scattered deuterons) were clearly resolved. At 20 deg. the triton and deuteron mean ranges differed by less than 3% and hence could not be resolved. Slit systems were used to define the number of tracks originating in a given swath across the photographic plate. This, together with the high degree of resolution of scattered deuterons from other charged particles (at 20 deg. the energy width at half maximum of the scattered deuterons was 3%), permitted precise determinations of the differential D-D scattering cross section. Accurate determinations of beam direction, beam energy, maximum beam energy spread, and purity of target gas were made from the same plates which yielded the cross section determinations.

231 Taschek, R. F., Argo, H. V., Hemmendinger, A., and Jarvis, G. A. "Neutron-Hydrogen Mass Difference from the $T^3(p,n)He^3$ Reaction Threshold." Phys. Rev. (2), 76, 325-7(1949).

The threshold for the $H^3(p,n)He^3$ reaction has been carefully measured using protons from the Los Alamos electrostatic generator and a thick target of H^3 absorbed in a Zr disk. The neutrons were observed at 0°, and the proton energy was measured relative to the accurately measured $Al^{27}(p,\gamma)Si^{28}$ resonance at 993.3 kev. The threshold for neutrons is found to be at a proton energy of 1019 ± 1 kev., giving for this reaction Q = −764 ± 1 kev. Assuming the rest mass of the neutrino to be zero, and the maximum energy of the β-particle from the decay of H^3 to be 18.5 kev., 782 ± 2 kev. is obtained for the neutron-hydrogen mass difference.

232 Taschek, R. F., Jarvis, G. A., Hemmendinger, A., Everhart, G. G. and Gittings, H. T. "A Study of the Interaction of Protons with Tritium." Phys. Rev. (2), 75, 1361-5(1949). (AECD-2352; LADC-570).

The scattering cross section of H^3 for protons was detd., 45-150°, at 1.59 and 2.01 Mev.; values (per unit solid angle) lie between 0.14 and 0.27 barn. The reaction cross section for $H^3(p,n)He^3$ at 900-2200 kev. is 0-0.075 barn per unit

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solid angle. H was detd. in H^3 from the 45° p-p scattering. The neutron yield of the reaction is high and will make it a useful source. The threshold of 986 kev. is sharp, and can be used as a point on the energy scale of nuclear physics.

233 Taub, H. and Kusch, P. "The Magnetic Moment of the Proton." Phys. Rev. (2), 75, 1481-92(1949).

Nuclear gyromatic ratios and magnetic moments in terms of the Bohr magneton, and magnetic moments in units of the nuclear magneton are tabulated for many nuclides including H^1, H^2, H^3, He^3 and Li^6.

234 Tollestrup, A. V., Jenkins, F. A., Fowler, W. A. and Lauritsen, C. C. "Neutron-Hydrogen Mass Difference from the D-D Reactions." Phys. Rev. 75, 1947-8(1949).

The energy release in the reactions $H^2 + H^2 \to H^3 + H^1 + Q_1$ and $H^2 + H^2 \to He^3 + n^1 + Q_2$ has been determined by measurement of the energy of the singly-charged H^3 and He^3 ions produced in a heavy ice target at a known angle with a deuteron beam of well-defined energy. The results have been $n^1 - H^1 = (Q_1 - Q_2) + (H^3 - He^3)$. The H^3 and He^3 ions were detected with a scintillation counter. Fluorescent light from the scintillations was collected by a hemispherical mirror, brought out through a Lucite window, and focused on the cathode of a 931-A electron multiplier. The energies of the H^3 and He^3 ions emerging from the target in the angular interval 134.5 to 141.1 degrees were measured by means of a double-focusing magnetic spectrometer. The curves of the number of counts as a function of the energy of the H^3 and He^3 ions, for a bombarding energy of 249 kev., are shown. The following Q-values were obtained as weighted averages: $Q_1 = 4.036 \pm 0.022$ Mev., $Q_2 = 3.265 \pm 0.018$ Mev., $Q_1 - Q_2 = 771 \pm 6$ kev. The results for Q_2 are substantially in agreement with other recent determinations. The value of Q_1 is significantly higher than the value $3.98 \pm .02$ previously determined. From these data, $n^1 - H^1 = 7.89 \pm 6$ kev. and the binding energy of the deuteron = $2.221 \pm .006$ Mev.

235 Voikhanskii, M. E., Dzhelepov, B. S. and Sliv, L. A. "The β-Decay of Tritium." Doklady Akad. Nauk S.S.S.R. 66, 829-32(1949).

For $\mu = 0$, 0.005, and 0.010 the authors calc. f values of $(2.5, 3.0, \text{and } 3.4) \times 10^{-6}$, resp., where μ is the ratio of the mass of the neutrino to that of the electron, and f is as defined in the Fermi theory of β-decay. Calcd. curves are presented for the β-spectrum for the above values of μ, assuming the max. β-energy to be 17.9 kev. On the assumption that the $H^3 \to H^3$ decay is a ${}^2S_{1/2} \to {}^2S_{1/2}$ process distinct from positron emission, $|M|^2 rf$ is calcd. to be 2800 for $\mu = 0$, and 3900 for $\mu = 0.01$, where M is the transition matrix element and γ is the half-life of the β-decay. Present information only justifies stating that $\mu = 0.01$.

236 Wapstra, A. H. "Mass Defects of the Lightest Nucleons." Physica 15, 380-5(1949).

The mass defects of the following light isotopes have been calculated from mass spectrographic and nuclear reaction data, by means of the "least squares" method: H^2, H^3, He^3, He^4, Li^6, Li^7, Be^7, Be^8, Li^8, Be^9 and B^9.

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237 Williams, D. L. and Ronzie, A. R. Micro-Syntheses with Tracer Elements. XVI. The Synthesis of Hexestrol Labeled with Tritium. Los Alamos Scientific Laboratory. n.d. (AECU-714; LADC-750).

Information has been desired regarding the stability of organic compounds containing the isotope H^3 in place of H. Since a higher concentration of radioactivity can be imparted to an organic compound by means of H^3 than with almost any other element, this method of labeling should prove to be ideal for those chemical entities which produce profound biologic changes in the living system when present in exceedingly small concentrations. A group of compounds having such an effect are the sex hormones. Minute amounts of these chemical entities can bring about deep seated physiologic changes in both the male and female. One of the female sex hormones, "hexestrol" is synthetic in the sense that it does not occur naturally in living organisms, but is a very powerful estrogen. This compound may be easily labeled with H^3 and was accordingly chosen for study. Both meso- and racemic forms of hexestrol, labeled with H^3 were obtained by the hydrogenation of dienestrol with a palladium on carbon catalyst. The presence of a small amount of H^3 during hydrogenation exerted a very significant influence upon the rate of consumption of ordinary hydrogen under conditions which were otherwise identical.

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238 Bethe, H. A. "The Range-Energy Relation for Slow-Alpha-Particles and Protons in Air." Rev. Modern Phys. 22, 213(1950).

A critical evaluation of Q_2 in the reaction $Li^6 + n = He^4 + H^3 + Q_2$ is given.

239 Bigeleisen, J. "Dissociation and Exchange Equilibria of the Tritium Halides." J. Chem. Phys. 18, 481 (1950).

The ratios of the partition functions of the tritium halides to their respective protium halides have been calculated. These are combined with one another to give the exchange equilibria between the six pairs of tritium and protium halides. The exchange equilibria with water are calculated. From the exchange equilibria between the tritium halides and protium and the free energy of dissociation of the protium halides, the dissociation equilibria of the tritium halides have been calculated. The experimental data on the dissociation of HI are reviewed and it is shown that the data of Taylor and Cristron DI and HI are self-consistent as well as good agreement with theory. The heat of formation of HI at absolute zero is found to be 1007 ± 10 cal./mole. By means of suitably chosen exchange equilibria, which can be calculated directly from partition functions ratios, it is possible to calculate all the thermodynamic equilibrium constants for gaseous H^3 compounds from the experimental and theoretical values for the corresponding protium compounds. Gives ratios of partition functions for

$$\frac{H_2^3}{H_2^2}, \frac{HH^3}{H_2^2}, \frac{H^3F}{HF}, \frac{H^3Cl}{HCl}, \frac{H^3Br}{HBr}, \frac{H^3I}{HI}$$

as a function of temperature.

240 Brues, A. M. and Stroud, A. N. "Effects of Tritium on Cells Cultivated in Vitro." Anat. Record 106, 181(1950).

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This is an abstract of some material that appears in ANL-4451.

241 Camerini, U., Fowler, P. H., Lock, W. O. and Muirhead, H. "Nuclear Transmutations Produced by Cosmic-Ray Particles of Great Energy. Part IV. The Distribution in Energy, and the Secondary Interactions of the Particles Emitted from Stars." Phil. Mag. (7), 41, 413-28(1950).

The measurements of "multiple scattering" and "grain density" discussed in Parts II (Phil. Mag. 40, 1073(1949)) and III (Phil. Mag. 41, 169(1950)) of the present series of papers, have now been extended to include a total of 1000 tracks of particles associated with "stars." The method of measurement and the criteria for the selection of tracks were similar to those described previously (III). The new material provides additional evidence in support of the view that most of the mesons ejected from nuclear explosions with kinetic energy less than 150 Mev. are π-particles. The distribution in energy of the ejected mesons, protons, deuterons, and tritons has been determined, and it is shown that the "spectrum" for the mesons is in good agreement with that calculated by Sands (Phys. Rev. 77, 180(1950). The mean free-path for nuclear interaction of the various types of particles in passing through the emulsion has been determined. The value obtained for mesons corresponds to a cross section for the interaction equal to the "geometrical" value.

242 Cooper, E. P. and Rogers, F. T., Jr. "Composite of Experimental Measurements of the Energy-Distribution Among Beta-Particles from Tritium." Phys. Rev. 77, 402-3(1950).

The β spectrum of H^3 lies at such low energies that relativistic effects may be neglected. Since the screening effects are also small in this case, the β decay of H^3 should provide a simple and critical test of the Fermi theory at low β energies. The authors have constructed a composite of the various published spectra and compared this plot with a theoretical Fermi plot using the nonrelativistic Coulomb factor. In general the agreement between the curves is good, although small deviations are found below 2.5 and above 18 kev.

243 Dieke, G. H. Annual Report, 1949. Johns Hopkins University. Feb. 1, 1950. (JHU-4).

This report summarizes the work carried out during the past year on the spectra of H molecules containing H^3 and on related subjects. The purpose of the work was to determine the detailed structure of the H molecule by studying its spectrum. The immediate object of the work was to photograph the spectra of H^3H, H^3_2, and H^3H^2 and analyze them. Appendix 1 is a bibliography of 149 references to papers on the molecular spectra of hydrogen since 1922.

244 Goward, F. K., Titterton, E. W. and Wilkins, J. J. "Observations of (γ,T), (γ,D), and (γ,np) Reactions in Boron." Proc. Phys. Soc. (London) 63A, 172-3 (1950).

In boron-loaded Ilford emulsions, bombarded with γ rays, stars were observed which are consistent with the reactions: (1) $B^{11} = H^3 + 2He^4 - 11.1$ Mev. (2) $B^{10} = H^2 + He^4 - 5.8$ Mev.

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The events are identifiable by an examination of the momentum balance of the particles forming each star, a procedure which gives ready differentiation from "carbon stars," and which, in most cases, makes it possible to assign the events to either reaction (1) or (2). A number of stars were also observed for which the momentum could not be balanced, some of them consistent with the reaction $B^{10} = n + p + 2He^4 - 8.0$ Mev.

245 Hemmendinger, A. Interaction of Tritons with Protons and Tritons. Los Alamos Scientific Laboratory. July, 1950. (TID-372).

Discussion of apparatus, methods, and results for H^3-H^1 and H^3-H^3 scattering, and similar experiments carried out at Los Alamos.

246 Hodgson, P. E. "Heavy Fragment Disintegrations." Nature 165, 355(1950).

A star has been observed in Ilford G5 nuclear research emulsion exposed on the Jungfraujoch. It consists of three lightly ionizing particles and three singly charged particles emitted nearly in the same direction. The ranges of these particles, which all end in the emulsion, are 31μ, 61μ, and 88μ, respectively, which is nearly in the ratio 1:2:3. The deviations from exact proportionality may be accounted for by straggling. These tracks are attributed to a triton, deuteron, and proton, respectively. The event may be explained by assuming that an excited Li nucleus was ejected from a nucleus by a cosmic-ray particle and subsequently disintegrated in the following manner: $Li^6 \rightarrow H^1 + H^2 + H^3 - 21.3$ Mev. This reaction is not the most favorable reaction energetically. However, if the spins of the disintegration products are all parallel, the total spin of the products is 2, whereas the alternative processes give products with spin 1. If the spin of the excited nucleus is 2, the other reactions will be forbidden. In another observed event, two tracks of singly charged particles with nearly equal range and in the same direction are observed. These tracks may be attributed to either of two reactions: $He^4 \rightarrow 2H^2 - 12.8$ Mev., $He^6 \rightarrow 2H^3 - 12.2$ Mev.

247 Hu, T. M. and Hsu, K. N. "Binding Energy of the Triton." Phys. Rev. (2), 78, 633-4(1950).

Calculations are made using various assumptions.

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An accurate determination of both the half-life and the average energy of H^3 β decay has been made. The half-life was determined by measuring the rate at which the decay product He^3 was formed from a measured quantity of H^3. The average energy was determined by calorimetric measurement of the power generated by the same sample. A value of 12.46 ± 0.09 yr. was found for the half-life, and a value of 5.69 ± 0.04 kev. was found for the average energy of the decay of H^3 to neutral He^3. 11 references.

249 Kritchevsky, D., Biggs, M. W. and Freeman, N. K. Preparation of Tritiated Cholesterol. Univ. of

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California Radiation Laboratory. March 24, 1950. (UCRL-644).
Method used and amount of H^3 in purified product is given. H^3 content too small to cause change in infrared spectrum.

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250 Laurence, W. L. "The Truth About the Hydrogen Bomb." Sat. Evening Post 222, No. 52, 17-19, 20 93, 94(1950).
A popular treatment of the use of H^2 and H^3 in the fusion, or H-bomb.

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